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PHYSIOLOGICAL BASIS OF TRACTOR DESIGN

By G. LEHMANN

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Energy expenditure of tractor driving varies from 1–4 kcal/min depending on the particular agricultural task performed. The paper is concerned with principles underlying the design and positioning of tractor controls and seats in such a way as would enable the operator to carry out this strenuous work under the most favourable conditions.

Energy consumption and electrical skin capacity of the operator were measured during tractor driving with a number of different types of seat. The most satisfactory seat had a parallel seat suspension and hydraulic damping of tractor vibration. The extra cost of this seat above that most commonly supplied was insignificant in relation to the total cost of the tractor.

A study was made of the positioning relative to the operator of brake and clutch pedals, foot rest, steering column and steering wheel. The techniques employed in this study were : measurement of O_2 consumption and heart rate of the operator and of forces required in depressing the pedals and turning the steering wheel. In each instance the optimal positions of control and operator are illustrated by a detailed diagram.

In many existing tractors there is a separate brake pedal for each wheel (for rapid turning) and for both wheels together (for braking). A new type of brake with a single pedal (accident proof) is described. This brakes both wheels unless the steering wheel is also turned, when the brake on the outer wheel is released.

A standard commercial tractor was modified according to the principles described. Energy consumption of operators was found to be 13–29 per cent below that with unmodified equipment and the heart rate 40–45 per cent lower. It is believed that fatigue is reduced more than the energy figures suggest.

THIS paper is a brief summary of investigations carried out in Germany by a team of physiologists, engineers and agriculturists (Dupuis *et al.* 1955). Our first step was to review the construction of various types of tractors. We found that they differed widely as to the arrangement of the operating controls. Each manufacturer tries to find the best technical solution of the problem of assembling the different parts of the tractor in the smallest space, without paying much attention to the fatigue and strain the product may cause to the operator.

Rather than construct a new tractor, it was our aim to develop the underlying principles for the arrangement of the various controls so as to permit the tractor operator to work under the most favourable conditions.

The need to improve tractors in this way results from the fact that the physical stress on the tractor driver is considerable. Even when rather light work is done with the tractor, we rarely find the energy consumption of the operator below 1 kcal/min above resting level. Moderately heavy work, like mowing, or hoeing potatoes, or sometimes even just driving the tractor over a bad lane, may require up to 1·7 kcal/min ; ploughing reaches 2·5 kcal/min and front loading up to 4 kcal/min (Figs. 1 and 2). It is evident that using a tractor can be more strenuous than doing the same type of work manually, although, of course, the output is considerably higher by machine. Besides this, many tractor drivers suffer from gastric ulcer or other gastric complaints which may

be due to the vibrations to which they are exposed. Gastric disease has to be regarded as a true occupational disease of tractor drivers.

In order to determine what operating elements should receive special attention, in a first series of experiments we recorded the frequency with which the various foot and hand controls of the tractor were used in different kinds

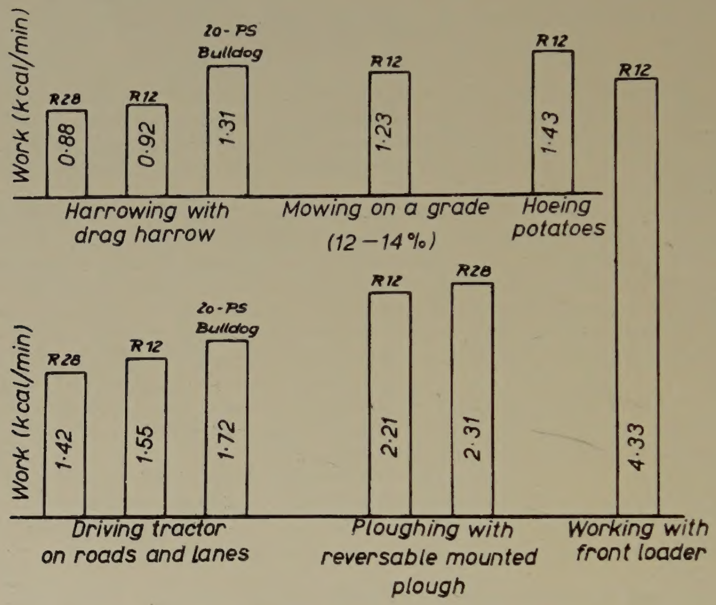

Figure 1. Energy expenditure of tractor driver operating three different types of tractor on various farm jobs.

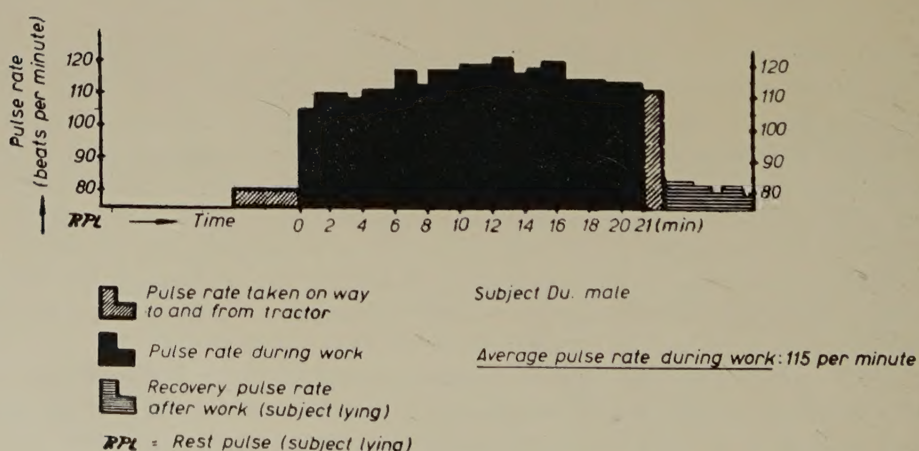

Figure 2. Pulse rate of tractor driver while loading manure with front loader.

of work. At the same time, we recorded what forces had to be exerted to operate the hand levers and pedals. Respiration and pulse rate measurements showed the load imposed in normal tractor operation. On a test course, range and angles of sight, which are of special importance for tractor driving, were registered photographically.

Very important for the driver's comfort is the construction of the seat. We examined a number of seats of different construction. It was found that driving without load on a bad road, with a parallel suspension seat*, required less energy than with a non-parallel suspension. Those seats which transmit all jars and jolts to the driver's body are the worst. The most suitable seats are those which combine the parallel seat guide with hydraulic damping of the vibrations.

Besides the measurement of energy consumption, we used the electrical capacity of the skin as a criterion of 'vegetative stress'. This method proved valuable for the investigation of vibration, and yielded results that corresponded well to the subjective judgments of the drivers (Fig. 3).

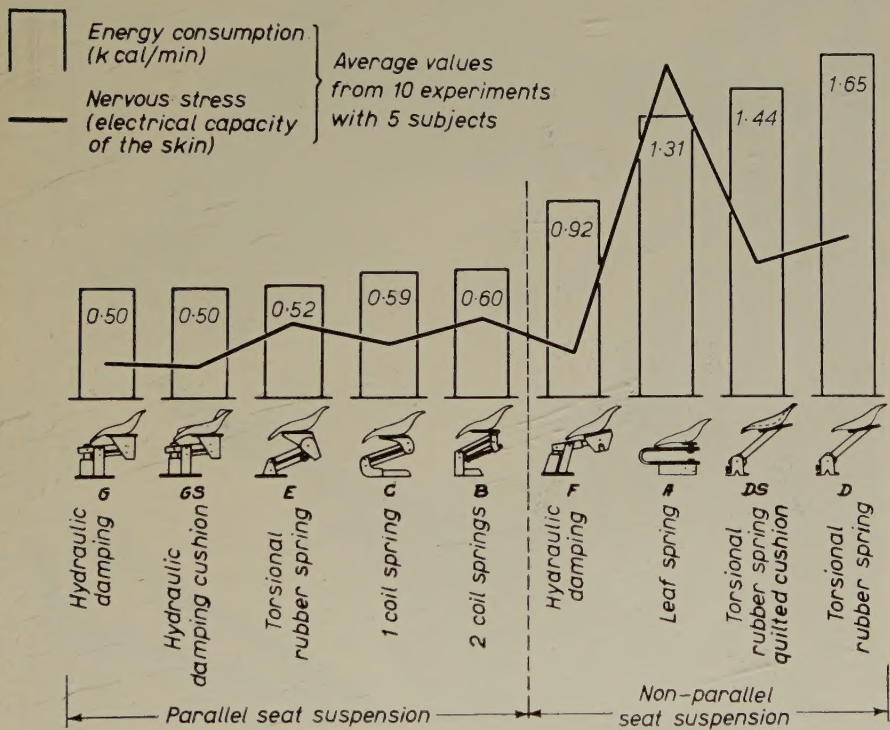

Figure 3. Effect of vibrations on energy expenditure and electrical capacity of the skin, subject seated on various tractor seats.

Among the non-parallel suspended seats, the leaf-spring suspended seat proved particularly bad with regard to the 'vegetative stress' of the operator. About 80 per cent of all tractors are provided with this seat or one of similar construction, very likely because it is the cheapest. The difference in price, however, between the cheapest and the best seat is so low that it is actually insignificant in relation to the cost of the tractor.

* A seat suspension designed with a parallelogram linkage so that the seat always moves parallel to itself.

Figure 4 shows an upholstered seat which proved particularly good. The location of the seat was determined by the body size of the operator and the length of his legs and by the angle with the horizontal at which the clutch and brake pedals are worked. The most favourable angle is known from previous investigations (Müller 1937). Figure 5 shows how closely the optimum angle may be approached in practice. As the angle between the legs is increased, the maximum exertible force diminishes, thus pedals on which a large force is exerted should be located as close to the mid-line as possible (Fig. 6).

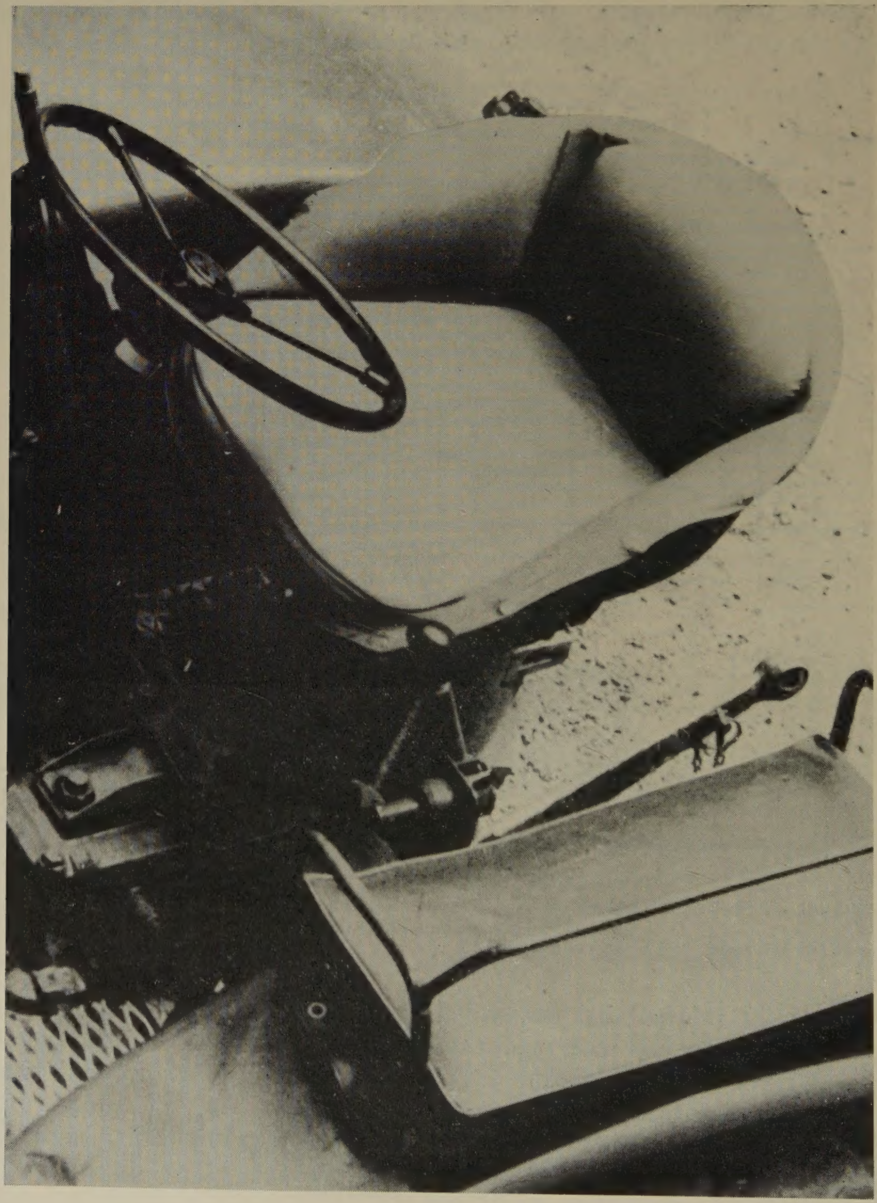

Figure 4. Upholstered tractor seat developed by the Max-Planck-Institut für Arbeitsphysiologie, Dortmund.

The best shape for the accelerator pedal was studied on a laboratory mock-up, the precision of speed regulation and foot comfort being used as criteria (Fig. 7). The measurements were carried out with varying restoring forces on the accelerator pedal. The apparatus also simulated jerks similar to those of a moving tractor. In experiments without the jerk simulator, the most favourable restoring force for the accelerator, resting against the ball of the foot,

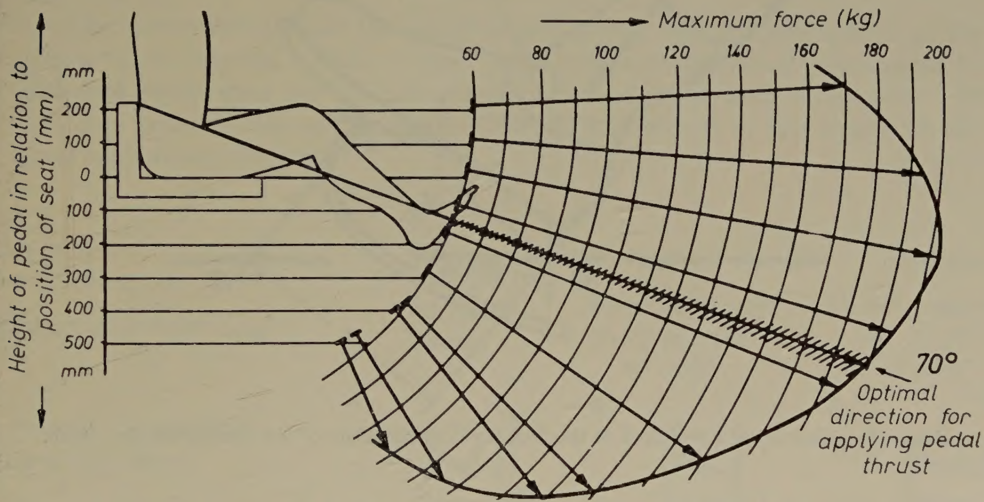

Figure 5. Maximum pedal-thrust in relation to height of seat above pedal.

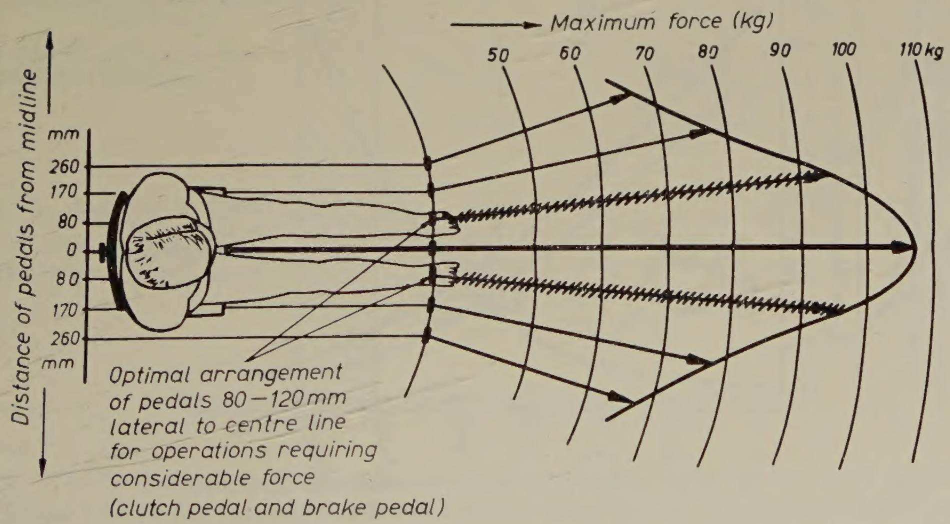

Figure 6. Relation of maximum pedal thrust to lateral angular separation of legs.

amounted to 3 or $3\frac{1}{2}$ kg. When the jerks were superimposed, the optimum value rose to 4 kg. The lower value corresponds rather well to the pressure the foot exerts merely by its own weight when all muscles are totally relaxed. It is therefore recommended that a somewhat larger readjusting force should be used than corresponds to the effective weight of the foot.

The ankle joint is so sensitive to tilting movements that a maximum angle of 20 degrees between idling position and full acceleration is sufficient. The ball of the foot and the accelerator pedal then move through a distance of 40 mm.

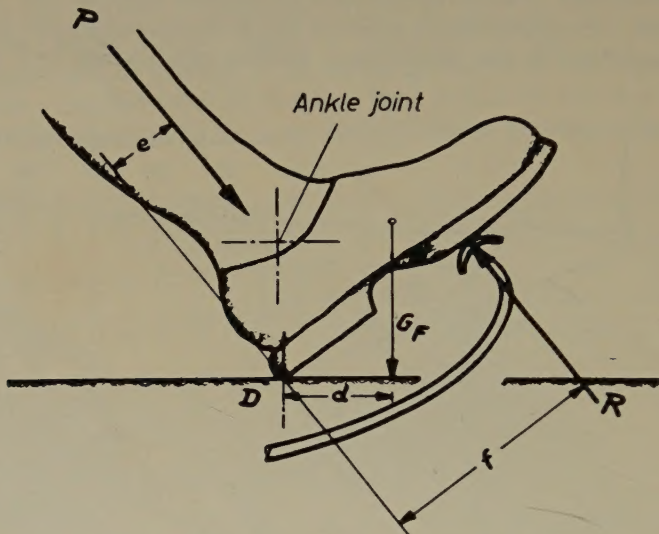

Figure 7. Mechanical conditions at the foot for determination of the pedal restoring force.

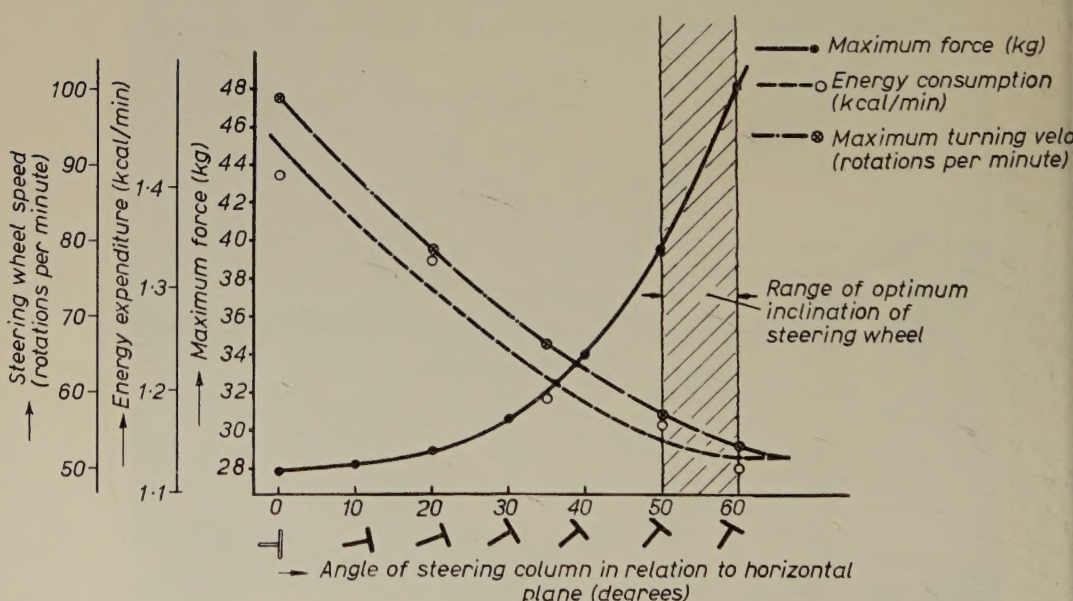

Figure 8. Maximum force, energy consumption, and maximum turning velocities with various inclinations of the steering-wheel.

In most tractors these distances are actually much greater, and in a few they are smaller. If this distance of travel is too great, the foot is forced into uncomfortable and fatiguing positions.

The most suitable location of the steering-wheel resulted from an investigation of the energy cost of steering and of the force and speed achieved. The

largest force can be exerted on an almost horizontal steering-wheel. On the other hand, the steering-wheel may be turned with the greatest velocity if it is nearly vertical. With this vertical position of the wheel, however, the energy consumption is very high, and is smallest with the steering-wheel inclined so that its axis (i.e. the steering-column) makes an angle of 50–60 degrees with the horizontal. In this range only 70 per cent of the maximum force is achieved but this position of the steering column must be considered the most favourable one (Fig. 8).

The driver should hold the wheel in such a way that the arm is bent at the elbow by 87 degrees. This is often impossible with the usual adjustment to different body sizes by a forward and backward movement of the seat. It becomes possible, though, by an additional adjustment of the length of the steering-column (Fig. 9).

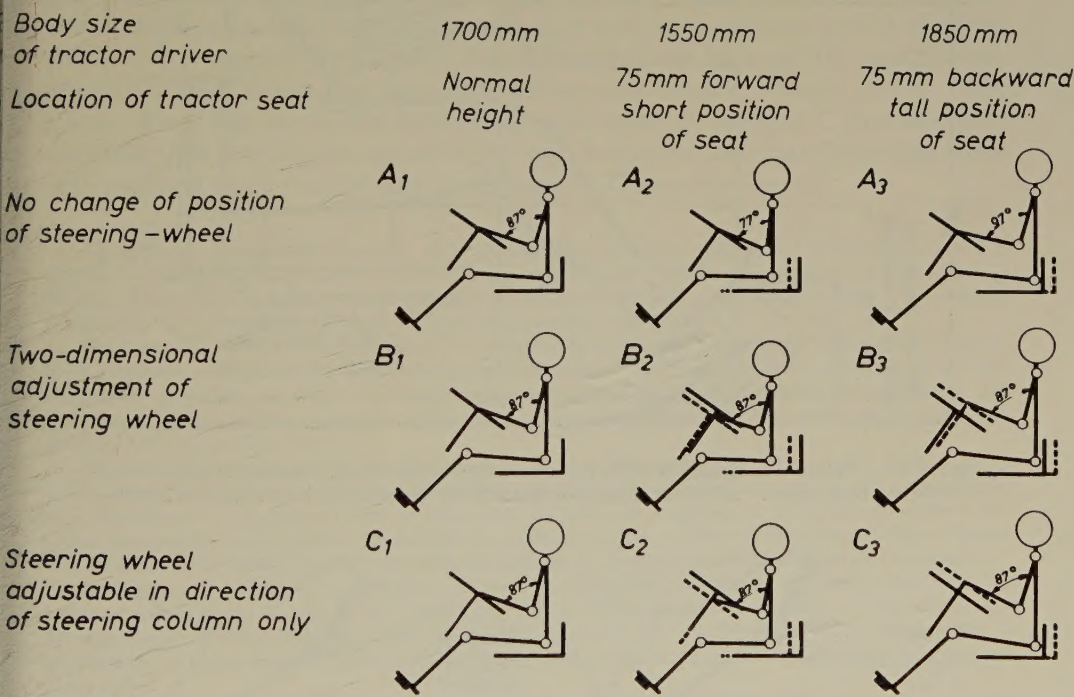

Figure 9. Adjustment of steering-wheel to various body sizes.

The brakes are used either to restrict the velocity of the tractor or as single-wheel brakes for turning the tractor in a limited space. There are, therefore, tractors with three braking-pedals where the erroneous operation of one of the single-wheel brakes might be dangerous with speedy driving. There are also tractors with two braking-pedals which, when individually operated, work on a single wheel and when linked together work as a normal brake. Even this arrangement, however, cannot be considered accident-proof. Therefore we designed a new brake with a single pedal which normally brakes both wheels. If the steering-wheel is inclined beyond a certain point, however, the brake of

the outer wheel is automatically released. This simple arrangement is accident-proof and allows the braking-pedal to be located within the convenient operating space.

The clutch-pedal is used very frequently. We observed that the force exerted on the clutch-pedal is generally far greater than necessary. Obviously the driver cannot notice the moment when the clutch is actually released. To avoid this waste of energy, the following simple device proved to be of value. For several reasons it seemed practical to fit the tractor with a bottom plate which is curved upwards in front in such a way that it provides a comfortable

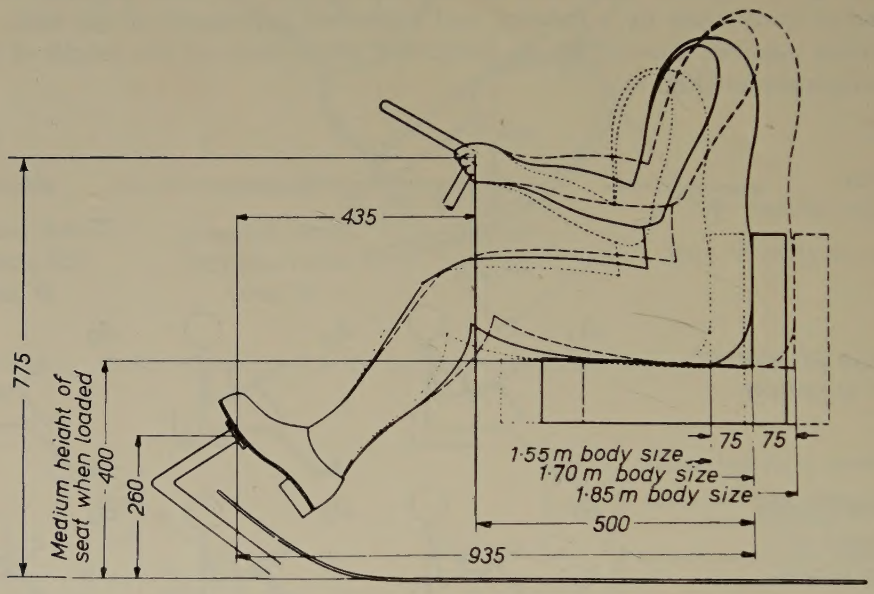

Figure 10. Relative positions of seat, pedals, and steering-wheel. Range of adjustment to different body sizes. All dimensions are in millimetres except where stated otherwise.

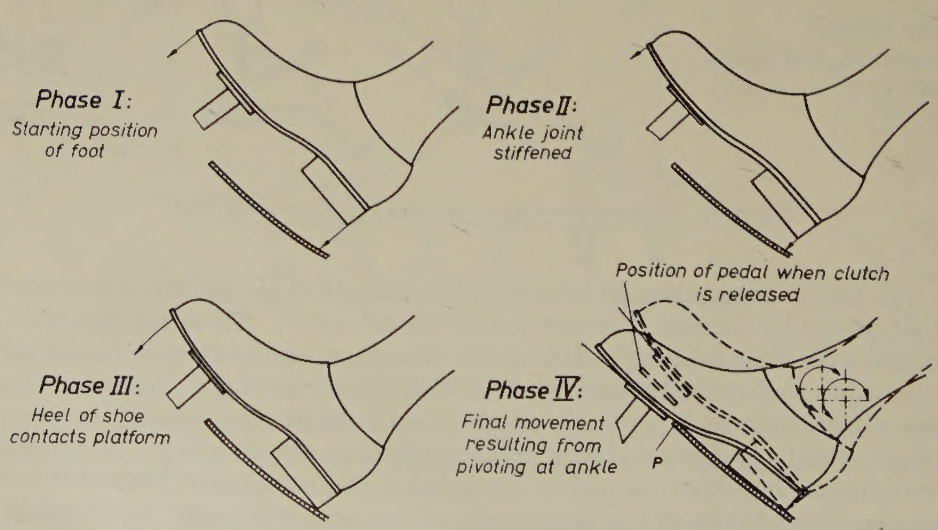

Figure 11. Phases of movement while operating clutch-pedal.

foot-rest (Fig. 10). The plate is made from expanded metal and is therefore transparent, which may often be useful. The clutch pedal projects above this plate (see Fig. 10), and when it is pressed down, the sole of the foot will touch the plate at a certain depression. The clutch should be adjusted so that at this touching point it is fully released. On a closer study of this movement we found that the foot presses on the pedal until the heel reaches the bottom plate. The foot is then flexed at the ankle joint until the sole also rests on the bottom plate. The movement at the ankle joint takes place over a range of 12 degrees (Fig. 11).

After having established these principles and some others not discussed here, we applied them to a standard commercial tractor which was modified by the Institute's workshop. The result was still far from perfect, as we had to compromise on several points. A tractor which, from the start, is constructed according to these principles would certainly be much better. Still, it was pleasing to see our vehicle looking not like a peculiar and complicated machine, but still like a tractor! In some controlled tests we compared it with the best present-day tractors available. For different kinds of work the energy consumption was found to be from 13 to 29 per cent below the usual values. The pulse rate of the driver was lowered by from 40 to 45 per cent. This seems to indicate that the fatigue caused by cramped posture and static muscular work was lessened more than would correspond to the energy saved.

La dépense énergétique pendant la conduite d'un tracteur s'élève à 1–4 kcal/min, selon la nature de la tâche d'agriculture exécutée. L'article traite des principes de la construction et de l'emplacement des organes de commande et sièges de tracteur, qui permettraient à l'opérateur d'exécuter ce travail difficile dans des conditions les plus favorables.

On a mesuré la dépense d'énergie et la capacité de la peau de l'opérateur pendant la conduite d'un tracteur avec plusieurs différents types des sièges. Le siège le plus satisfaisant avait une suspension parallèle du siège et l'amortissement hydraulique de la vibration du tracteur. La différence entre le prix de ce siège et celui du siège le plus commun était très petite en comparaison avec les prix total du tracteur.

On a étudié l'emplacement des pédales de frein et de débrayage, du repose-pied, de la colonne et du volant de direction. On a employé des techniques suivantes dans cette étude : mesure de la consommation d'oxygène et de la fréquence du pouls de l'opérateur, ainsi que la mesure des forces nécessaires pour presser les pédales et pour tourner le volant de direction. Dans chaque cas un schéma détaillé a illustré les positions optima de l'organe de commande et de l'opérateur.

De nombreux tracteurs employés à présent ont un pédale de frein pour chaque roue (afin de tourner rapidement) et un autre pédale pour deux roues ensemble (freinage). On décrit un type nouveau de frein avec un pédale (à l'abri de l'accident). Ce dispositif freine deux roues, à moins que le volant de direction ne soit tourné en même temps, ce qui débloque le frein de la roue extérieure.

On a modifié un normal tracteur industriel selon les principes décrits ci-dessus. On a trouvé que la dépense d'énergie des opérateurs était de 13–29 pourcent plus petite que celle avec le dispositif non-modifié ; la fréquence du pouls était de 40–50 pourcent plus basse. On prétend que la diminution de la fatigue est plus grande que ne l'indiquent les chiffres d'énergie économisée.

Der Energieaufwand während der Traktorführung beträgt 1–4 kcal/min je nach der Natur der ausgeführten landwirtschaftlichen Arbeit. Der vorliegende Aufsatz stellt die Grundlagen der Konstruktion und Einstellung der Bedienungsorgane und der Sitze des Traktors dar, die es dem Operator ermöglichen, diese mühsame Arbeit unter den vorteilhaftesten Bedingungen auszuführen.

Der Energieaufwand und die Hautkapazität des Operators wurden während der Traktorführung mit einer Anzahl verschiedener Sitze gemessen. Der die besten Resultate ergebender Sitz hatte eine parallel Sitzaufhängung, sowie die hydraulische Dämpfung der Traktorvibration. Die Extrakosten diese Sitzes im Vergleich mit dem gewöhnlich gelieferten waren gering in Bezug auf den Gesamtpreis des Traktors.

Man hat die Lage des Brems- und Kupplungsfusshebels, der Fussraste, der Steuersäule und des Steuerrades in Bezug auf den Operator studiert. Die in dieser Untersuchung angewandten

Arbeitsverfahren waren wie folgt : Messung des Sauerstoffverbrauchs und der Pulsfrequenz des Operators, sowie der zur Drückung der Fusshebel und zur Drehung des Steuerrades benötigten Kräfte. Die Optimallagen der Bedienungsorgane und des Operators sind für jeden Fall durch ein ausführliches Schema illustriert.

In vielen gegenwärtig angewandten Traktoren gibt es einen besonderen Fusshebel für ein jedes Rad (für schnelles Lenken), sowie einen für beide Räder zusammen (für Bremsung). Es wird ein neuer Bremstyp mit einem einzigen Fusshebel (unfallsicher) beschrieben, der beide Räder bremst, sofern das Steuerrad nicht gedreht wird, weil dann die Aussenradbremse ausgelöst wird.

Ein normaler industriemässiger Traktor wurde den beschriebenen Grundlagen gemäss abgeändert. Es wurde festgestellt, dass der Energieverbrauch des Operators um 13–29 prozent niedriger war als in der unabgeänderten Ausführung, wobei die Pulsfrequenz um 40–45 prozent niedriger war. Es wird beansprucht, dass die Ermüdung in einem grösseren Masse vermindert wurde, als dies aus den Energieziffern zu folgen scheint.

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METHODS OF TRAINING OLDER WORKERS

By Eunice Belbin
Medical Research Council

Three experiments are described which show subjects in middle age to learn more rapidly and thoroughly if they can do so by way of actual performance of the task rather than by memorization of instructions. The first two experiments used laboratory-type card-sorting tasks. The third involved training in the mending of worsted cloth. An experimental training method, which has been described in a previous article (Belbin *et al.* 1957), was compared with the traditional 'exposure' or 'sit-by-me' method. The experimental method aimed at removing the perceptual difficulty which had been found in previous experiments to be a limitation upon success in training young girls to mend. This method was found to yield even better results with middle-aged subjects than it had with school-leavers.

§ 1. Introduction

Most studies of learning in relation to age have shown older subjects to be at a considerable disadvantage. (see McGeoch and Irion 1952). In the majority of these studies literal reproduction has been used as the criterion of learning ability and memorization has assumed a central role. Previous experiments (Belbin 1956) have indicated, however, that while older people are very much inferior to younger at recalling in words information they have learnt, they may nevertheless be comparatively good at *using* it in a practical task. These experiments, and also those of Speakman (1954), indicate that *some* things can be learned at least as well by older people as by younger, and that the former are better at learning for 'use'—and at learning by 'using'—than at the artificial rote-memorizing tasks of the laboratory.

It is not only in the laboratory that older people are given tasks to memorize. The traditional methods of industrial training often involve learning the job by verbal description, where not only a mass of new terminology has to be memorized but also details from charts and diagrams. In the following experiments, therefore, we have attempted to develop a method of learning which minimizes conscious memorization; to investigate whether such a method is relatively advantageous to the older learner; and to ascertain the extent to which such a method can be applied to the learning of an industrial skill. The first two experiments were conducted with laboratory tasks; in the third we have compared two methods of teaching older people the skill of worsted-mending.

§ 2. Experiment I

Subjects were asked to 'post' 50 numbered cards into five slots in the lid of a box. Each slot bore a distinctive colour. There was a systematic relationship between colour and number. For example, all cards in the 20's had to be posted into the pink slot and all those in the 30's into the black slot.

The subjects had to learn the relationship between colour and number so that they could ' post ' cards as quickly as possible without making errors.

Two methods of training were used :

(*a*) *Learning by Memorizing*

The subject was given a chart showing the relationships between colours and numbers and left to memorize these, with the box into which the cards would have to be posted in front of him. When he was satisfied that he had learned the relationship, the chart was removed. His learning was tested by asking him to state the relationships. All subjects were able to do this accurately.

(*b*) *Learning by ' Activity '*

This method involved the subject in finding out for himself the relationship between colour and number. He was given a large pack of coloured cards, each of which bore a number, and told to ' post ' these cards into the appropriately coloured slots, noting the numbers as he did so, and gradually to build up the ideas of which numbers were associated with which colour. When he was satisfied that he had achieved this, he was transferred to the main task.

Each subject performed the task twice—once with the first and once with the second method of learning. Half performed first with the first method and then transferred to the second, and half performed the tasks in the opposite order. A different set of numbers and colours was used for each method.

The learning times, the times taken to post the 50 cards, and the number of errors were recorded.

Subjects

Since we were primarily concerned with teaching skills to industrial workers we attempted to use subjects who had an appropriate background. Accordingly 44 subjects whose ages ranged from 20 to 70, all of whom were drawn from among industrial workers or from rural evening institutes, performed the tasks. All of them had left school at the age of 14 and none of them had had any further academic training. The subjects were divided into four age groups, each with equal numbers of males and females.

2.1. *Results*

The results are shown in Table 1. With the Memorizing method the median times to post the fifty cards rose significantly from the twenties to the thirties and thereafter remained high, while the proportion of subjects with a completely correct performance fell sharply between the twenties and the thirties and fell again between the forties and fifties. With the Activity method the time to perform the task rose gradually from the twenties to the fifties but was never as high as that for the memorization method even amongst the oldest subjects. The quicker performance by the older subjects following training by this method was not achieved at the expense of accuracy, which tended to be greater with the Activity method in all the age ranges.

These results suggest that it was only when older subjects had learnt to do the task by memorizing the instructions that they were at any considerable disadvantage either as regards time or accuracy. However, it is possible that any or all of the following four factors might have contributed to these results :

Table 1. Median posting times after learning by two methods

Age range	Number in Group	Median posting time in seconds to post 50 cards		Percentage completely correct performances to total		Median learning time in seconds	
		Memorizing Method	Activity Method	Memorizing Method	Activity Method	Memorizing Method	Activity Method
20–29	10	96	96	60·0	70·0	33·5	54·0
30–39	12	152	112·5	33·3	66·7	60·5	115·0
40–49	8	150	122	37·5	50·0	77·5	122·5
Over 50	14	153	131	21·4	50·0	42·5	144·5

These results are tabulated for a point during the progress of performance at which the times taken by the younger subjects after training by both the methods were equal. The posting time of the twenties following training by the Memorizing method was significantly ($P<0{\cdot}01$) different from that of the thirties and also from those of the forties and fifties. The posting time of the twenties following the Activity method was not significantly different from that of the thirties or the forties, but was from that of the fifties ($P<0{\cdot}01$).

(*a*) The older people took substantially longer than the younger to learn, especially by the Activity method. It may have been that the older people were allowing themselves insufficient time to learn by memorizing. However, the length of time in learning by memorizing bore little relationship to length of performance time. For example, in the over-50 age group, the coefficient of ranked correlation between memorizing time and performance time was $+0{\cdot}61$, i.e. those who took least time to learn, tended to be those who performed the task most quickly. In addition, three subjects in the sixties who were unable to do the task at all after memorizing it, although they had repeated and lengthy additional learning periods, were able to perform it reasonably well when learning it by the Activity method.

(*b*) Learning by memorization involved ‘ translation ’ between the chart and box, which may have been relatively difficult for older people. In the Activity method, no such translation was involved, as the numbers to be associated with the colours were always seen going into the appropriate slots.

(*c*) Memorizing from the chart inevitably involved the learning of colour-number relationships as such, whereas with the Activity method it was possible to ignore the colours and to learn number-spatial relationships, which might conceivably be easier for older people.

(*d*) Finally, with the Activity method the task during the learning period was closely similar to the main task, and if older subjects, after learning by memorizing, had performed the main task for a longer time, they might conceivably have come substantially closer to the younger subjects and the times achieved by the two methods might have been considerably nearer together.

Experiment II was therefore designed to measure the effects of Activity learning as compared with those of Memorizing at different ages, with these four possibilities either eliminated or controlled.

§ 3. Experiment II

The task was to ‘ post ’ cards numbered from 20 to 79 into six different slots in the lid of a box. All the 20’s were to go to one slot, all the 30’s to another

and so on. The subject was required to learn the association between slots and numbers. Again there were two methods of learning :

(*a*) *Memorizing*

One group learnt to perform the task by memorizing small numbered slips which were attached to the slots in the box. These numbers were removed before the main task was performed. The subjects were asked to state where the numbers should be posted before commencing the experiment.

(*b*) *Activity*

This group had a pack of cards on which the pattern of the slots was printed. Each card bore one number against its appropriate position among the slots, as shown in Fig. 1, and it had to be posted into the slot indicated by that number. The subject was told to notice into which slots the numbers were placed. He was thus discovering the number–position relationship while performing the

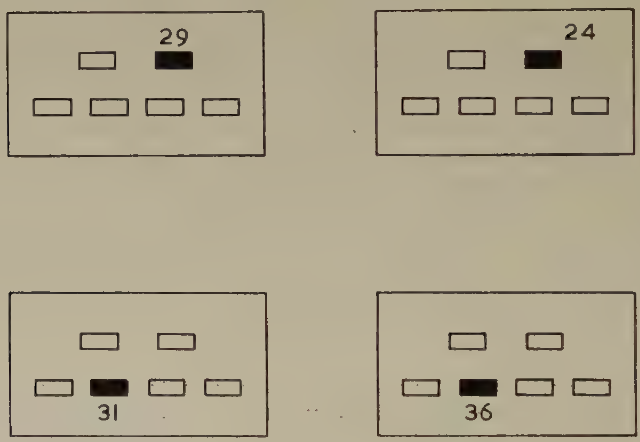

Figure 1. Examples of cards used during the 'activity' method of training in Experiment II.

task. Both groups were told to go on until they were satisfied that they had learnt the positions and were then transferred to the main task. The time taken to learn was measured by a stop-watch as was the time required for posting each six cards of the main task.

Subjects

For each learning method there were 8 subjects between the ages of 18 and 22 and 8 between 30 and 49. The younger subjects were naval ratings who had left school at 14, the older ones were trainees from a Government Training Centre, whose previous occupations were in the unskilled or artisan category and included labourers, factory workers, fishermen, lorry drivers, etc.

3.1. *Results*

Table 2 shows the times required by each age group by each learning method to reach an arbitrary criterion performance of 10 seconds to post six cards. With both methods of training the older subjects were slower than the younger to attain this target, but the difference was both absolutely and proportionately very much greater with the Memorizing method than with the Activity method. The younger subjects reached the target time more quickly after learning by

Memorizing than after the Activity learning : the older subjects, however, did so more quickly following the Activity learning method. The difference between the age groups in time taken to attain the target time after the Memorizing method is composed of differences both in learning time and in time for performance at the main task. With the Activity method, however, the older subjects were inferior only in length of learning time. The performance time they required to reach the target speed once the task had been learnt was very little different from that of the younger subjects.

Table 2. Times required in minutes and seconds to reach an arbitrary criterion performance of 10 seconds to post 6 cards

Method of learning	Age Group	Cycle at which the target was attained by the Group	i.e. after total learning time of		and after performing the main task for		Total time to reach target by the Group	
			min	sec	min	sec	min	sec
Memorizing	Young	12th	5	34	18	40	24	14
Memorizing	Older	27th	11	15	49	24	60	39
Activity	Young	7th	22	10	10	7	32	17
Activity	Older	6th	33	47	9	16	43	3

The figures may be analysed in a different way to show performances attained after constant time, adding together time taken learning and time taken performing the main task. This has been done in Table 3. Again it is possible to see the same pattern of results : the younger subjects doing better following memorization and the older showing better performance after learning by the Activity method.

Table 3. Average cycle time reached after 2027 seconds

Method of Learning	Age Group	Seconds per cycle
Memorizing	Young	9·5
Memorizing	Older	13·4
Activity	Young	10·3
Activity	Older	11·0

As in the previous experiment, both older and younger subjects were slightly more accurate after learning by the Activity method.

3.2. *The Significance of these Results for Industrial Training*

The results of both these experiments suggest that the decline in performance with age, which has been so consistently noted in the psychological research on learning, may in part be due to the learning method imposed by the experimeter. It seems that it is not possible to make an overall comparison between the learning capacities of different age groups of people in the abstract without taking into account the fact that the method of learning a task which is conducive to high performance by one group is not necessarily that which is conducive for the other. The present method of training people for a number of industrial tasks involves conscious memorization by the trainee. With this method of learning older people are likely to be at a disadvantage. This is not to say, however, that they will perform the tasks less well under all conditions : it appears that if an appropriate teaching method can be used they may be able to perform a number of tasks which have hitherto been regarded as outside their range of ability.

One such task is worsted mending in wool textile mills. In this industry it is maintained that all attempts to train older workers have proved unsuccessful. The operation is currently taught by description and demonstration. Our investigations into the difficulties encountered in learning this skill and the methods which we have developed to overcome them have been described previously (Belbin *et al.* 1956, 1957). In these experiments the performances of three groups of young school leavers were compared during and after 12 weeks of training by three different methods. In the following experiment we have investigated the extent to which it is possible to teach the mending skill to older workers when learning by memorization is minimized.

§ 4. Experiment III

Some idea of the lack of enthusiasm for training older people to mend in the worsted mills may be gained from the results of our appeal to recruit people over 30 for a 12-weeks training course. An experiment similar to that arranged for younger people was planned, using three groups of subjects. Some 400 firms who were members of the Woollen and Worsted Trades Federation were approached, but only two expressed any interest in the scheme. Accordingly, a modified form of the original experiment was designed and we recruited volunteers from outside the industry.

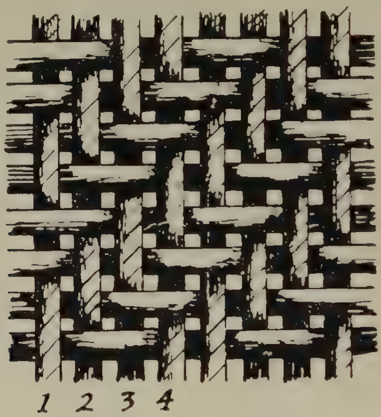

Figure 2. Example of a weave used in the mending experiment.

Experimental procedure

Twelve housewives between the ages of 30 and 50 were recruited. None had any experience of invisible mending. They were divided into two groups of six, and each was trained by one of the two following methods :

(*a*) *The Traditional 'Exposure' or 'Sit-by-Me' Method.*

This consists of working alongside an experienced mender who describes the weaves and demonstrates the method of mending them. Training periods normally last anything from 6 months to 2 years. The weave most commonly used in a number of mills—and therefore that on which most beginners are taught—is the 2×2 twill shown in Fig. 2. Trainees are told to 'go over two and under two', and to 'look for the float' to indicate where to place the needle. The older people who were trained by the exposure method in this

experiment were started off on this twill weave, and were trained by two experienced mender-supervisors from a worsted mill.

(*b*) *A New Experimental Method.*

Training by this method was carried out by the writer. The method is based on a theory that successful performance of a task depends on the initial acquisition not only of the correct method or the required motion pattern but of the correct perceptual ' cues ' which make the desired motion pattern possible. The perceptual skill cannot be developed effectively by verbal methods of instruction and training. The essence of the experimental method is rather that the trainee is conditioned to respond appropriately to perceptual cues and this is achieved through successive presentation of tasks in which the key perceptual features are emphasized and the correct responses to these are facilitated. The presentation is controlled by the trainer and varied according to the progress of the individual trainee. In this way the trainee learns the skill through experience and by understanding born of such experience. The experience, however, is gained in a much shorter time than ' on the job '. The method depends from the outset on a fundamental analysis of the skill involved.

In the present experiment the trainees were given practice on specially woven large scale weaves and were then told to copy them on a small frame, using thick elastic instead of thread. In this way they discerned the details of the weaves for themselves and were enabled to learn without any serious possibility of making errors. They were gradually transferred on to smaller weaves with the aid of industrial magnifiers when they had become accustomed to mending a particular weave structure. Thus at no time was the task too difficult for them.

Each group was given 8 hours instruction in mending three basic weaves and one smaller weave. This was followed by 12 hours further practice. Two of the 8 hours of Experimental training were spent with the special training devices. The group trained by the Exposure method spent the whole 8 hours on actual production work.

Time tests were given at intervals during the 20 hours. Each subject was asked to sew 3 in. and 6 in. single mends on three of the weaves most commonly used in the industry. This involved replacing a missing warp or weft thread in a plain 1 × 1 weave, a 2 × 2 hopsack and a 2 × 2 twill. Later in the course they were required to sew a double mend, i.e. two missing threads. The material to be mended had been retained from the tests given in the younger trainees' courses so that strict comparison was possible.

The trainees in the two groups were equated as far as possible for age and economic background. The age distribution is shown in Table 4.

Table 4. Numbers of subjects in Experiment III

Age range	Experimental Group	Exposure Group
30–35	2	1
35–40	2	3
40–45	–	1
45–50	2	1

4.1. *Results*

Comparison of the two methods for training older subjects

After 2 hours' training in the Exposure Course one trainee resigned. She had been unable to do the work at all and had no confidence in being able to continue. The times taken by the remaining eleven trainees to complete 6-inch

mends after 8 hours' training are shown in Fig. 3. It can be seen that the Experimental group tended to mend much more quickly than the Exposure group. This was especially so of the Hopsack weave in which the slowest of the six trainees in the Experimental Group took less time than the fastest of the group trained by the Exposure method. Also, three of the latter group mended the 2×2 twill inaccurately, while only one of the former group was unable to complete this mend.

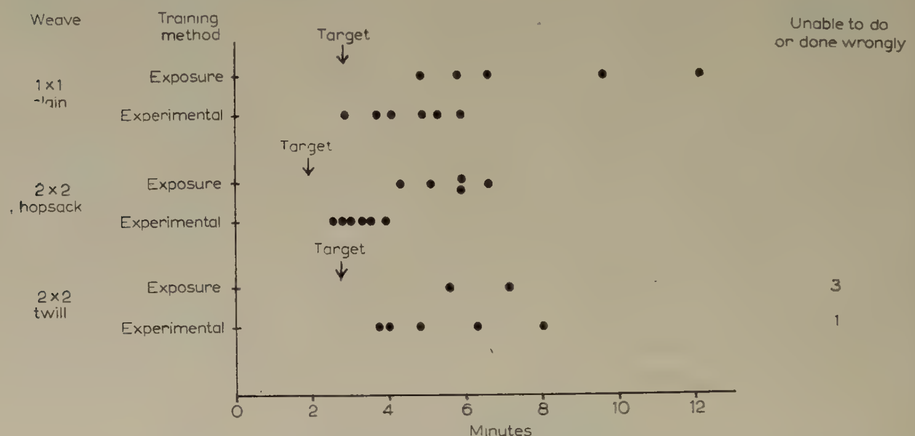

Figure 3. Times taken to mend 6 in. of weaves after 8 hours' training.

There were significant differences (on t tests) between the means of the performances of the two groups on the 1×1 plain ($P < 0{\cdot}05$) and on the 2×2 hopsack ($P < 0{\cdot}001$). It was not possible to make a similar test of comparison with the twill, since four of the eleven trainees were unable to do the test.

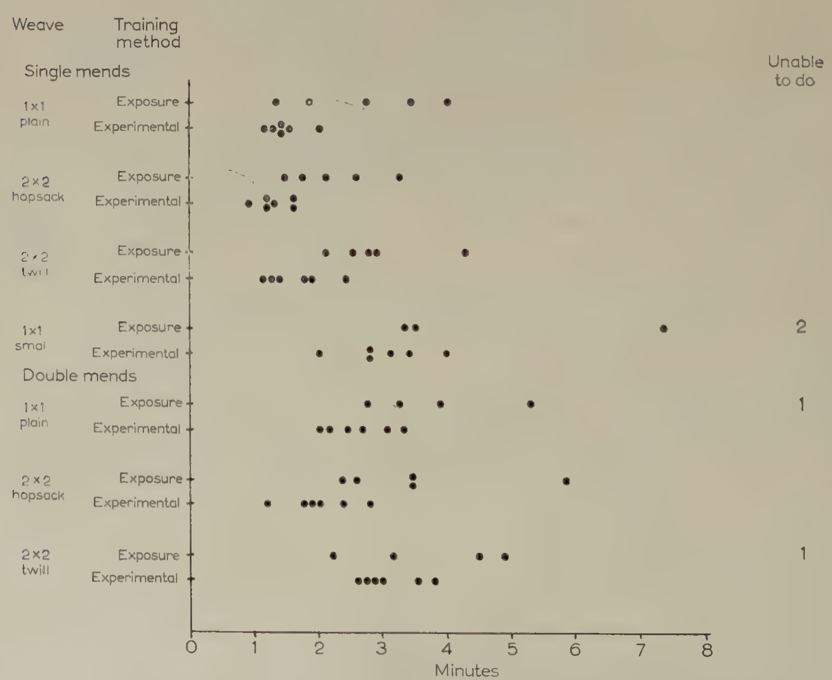

Figure 4. Times taken to mend 3 in. of single weaves and 2 in. of double. These are the lowest recorded times for each subject during 20 hours of training.

The times taken for the shorter mends are shown in Fig. 4. It is again evident that the group trained by the Experimental method was considerably faster.

Figures 3 and 4 bring out the point, noted in previous experiments, that variation between the performances of different individuals is greater after training by the Exposure method than after training by the Experimental.

The performance of these older subjects were in many respects remarkably good. For example, in the Experimental Group, one woman, aged 47, had reached 'target time' on the 1×1 plain weave after 8 hours' training. These targets were assessed by examining the performance of experienced menders in the trade.

Comparison with Training schemes for younger people

Experimental method. The performance of the experimental group of older trainees may be compared with two groups of younger people from the Training Centre in our previous experiments. Table 5 shows the period after commencement of training when the median performance times after 8 hours' training shown in Fig. 3 were attained by the younger groups of subjects. It may be noted that in a matter of hours the older people had learnt to mend at a rate which it had taken the younger group several weeks to attain. It must not be assumed, of course, that the older people were able at this stage to maintain their rates of production for any lengthy period. They were not given any tests involving sustained effort.

Table 5. Times taken by older and younger trainees to attain equal median times to mend 6 in. of weave

	Median times taken to mend 6 in. by older people who learnt by the Experimental Method	Amount of training necessary before these median times were attained by: Older people	15-year old school leavers: Experimental Method	15-year old school leavers: T.W.I. Method
Number of subjects:		6	10	10
Weave				
1×1 plain	4·5 min	8 hours	$5\frac{1}{2}$ weeks	7 weeks
2×2 hopsack	3·1 ,,	8 ,,	10 ,,	Not at all
2×2 twill	5·5 ,,	8 ,,	3–4 ,,	4 weeks

With the Hopsack material every member of the Experimental older group was able after 8 hours to mend 6 in. in under four minutes. It was not until the 12th week of training that every member of the Experimental group of school leavers in the Training Centre was able to mend at this rate. At no stage of the twelve weeks training was every member of the group of school leavers trained by the T.W.I. (Training Within Industry) method able to mend 6 in. of Hopsack in under four minutes: at week 12 three of the total group of 10 were still taking considerably longer.

A further comparison may be made with another training course for school-leavers, this time in a factory. Table 6 shows the median performance times for mending 3-in. single mends and 2-in. double mends by the Experimental group of older people during their first 20 hours of training. Column 2 of the table shows the period after commencement of training when the young

factory subjects trained by the Experimental method achieved similar mending rates. Again it can be seen that the older people attained a performance in a matter of hours which the younger girls had taken several weeks to acquire.

Table 6. Times taken by younger trainees to attain speeds at short test mends equal to those of older subjects during 20 hours of training. All subjects were trained by the Experimental method

	Older Group: Median performance times for mending a weave during the first 20 hours of training	Younger group trained in a factory: Period of training at which this median speed was attained by the younger people
Number of subjects:	6	4
Weave and mend		
1 × 1 single	1·4 min	Week 7 to 8
2 × 2 single	1·23 ,,	Week 7 to 8
2 × 2 twill single	1·55 ,,	Week 4 to 5
1 × 1 single (smaller weave)	2·95 ,,	Week 6 to 7
1 × 1 double	2·6 ,,	Week 7
2 × 2 double	2·95 ,,	Not at all
2 × 2 twill double	2·9 ,,	Week 7

The single mends were 3 in. long.
The double mends were 2 in. long.

Exposure method. Although the older people trained by the exposure method had a slower performance than those trained by the Experimental, their performance compared reasonably well with that of younger trainees. Table 7 shows the median performance attained by the older people after 20 hours' training by the Exposure method, together with the number of younger people trained by the same method who had still not reached these median levels after the 12 weeks of training.

Table 7. Median performance times for mending 6 in. of a weave. All subjects trained by Exposure method

	Older Group: Median performance Times for 6 in. mend after 20 hours' training	Younger Group: Number of trainees who were worse at Week 12 than the older people's 20 hour median
Number of Subjects:	5	8
Weave		
1 × 1 plain	5·6 min.	1
2 × 2 hopsack	4·2 ,,	4
2 × 2 twill	5·5 ,,	1
1 × 1 plain double	11·7 ,,	3
2 × 2 plain double	10·5 ,,	3
2 × 2 twill double	13·5 ,,	3

It was difficult to compare the mending performances of different groups on various weaves : some individuals might, for example, have had more practice on some weaves and less on others. It was decided, therefore, to calculate a combined ' mending rate index '. This index was the sum of the target times divided by times actually taken for each of the various weaves. The target times were, as we have already mentioned, based upon the performances of experienced menders studied in the worsted mills. The index was assessed

on the tests which were common to all groups, namely, 6-in. mends of 1×1 plain, 2×2 hopsack, 2×2 twill, 1×1 plain double, 2×2 hopsack double and 2×2 twill double. The indices for the various groups are shown in

Table 8. Mending Rate Indices for mending 6 weaves

	Older Group 20 hours training		Training Centre Groups 12 weeks training			Factory Groups	
Mending Rate Index	Experimental	Exposure	Experimental	T.W.I.	Exposure	Experimental training for 10–12 weeks	T.W.I. training for 15–31 weeks
6·26				√			
5·65	√						
5·64	√						
5·57	√						
5·53				√			
5·38				√			
5·38					√		
5·37			√				
5·30				√			
5·17							√
5·03	√						
4·83						√	
4·73			√				
4·68					√		
4·68		√					
4·64			√				
4·64						√	
4·59			√				
4·56						√	
4·52							√
4·37			√				
4·28			√				
4·23			√				
4·15					√		
3·86	√						
3·81					√		
3·81					√		
3·79			√				
3·67		√					
3·65				√			
3·64	√						
3·62			√				
3·43					√		
3·35						√	
3·28				√			
3·10				√			
2·87				√			
2·86					√		
2·84							√
2·77		√					
2·71					√		
2·37				√			
1·99							√
1·93		√					
1·41		√					
0·78					√		

Table 8. The relatively good performance by the Experimental older group at the end of 20 hours training as compared with the other groups after approximately 12 weeks or more training is apparent from this Table. It may also be noted that in these comparisons the older people were on the

whole better than the young after the Experimental training, but that after the Exposure training the older people were worse than the young.

The nature of the difficulty in mending

One factor which might have been an advantage to the older people was that they were all able to sew fairly well. However, this ' motor ' aspect of the task could not on its own have been of major importance since firstly, we had already found that among the younger groups there was no correlation between the results of an initial Needlework Selection Test and performance at the end of training; and secondly, although the members of both the older groups were equally efficient needlewomen, the standards of performance they attained differed very significantly between the two training methods.

It was clear from observation and from discussion with the trainees that the main training problem, especially for the older people, was to enable trainees to perceive the weaves. All six trainees in the older experimental group agreed that the most helpful form of instruction was the initial practice on large-scale weave structures. From these large weaves they were well able to understand the visual task of where to insert their needle when either a warp or a weft thread was missing. When they were then given the smaller weaves transfer from one task to another was comparatively easy. On the other hand, the older group trained by the Exposure method were quite at a loss to ' understand ' where to insert their needles either when commencing the simplest 1×1 or 2×2 plain weaves or at any time during attempts to mend a twill. As one of these trainees expressed it " . . . the difficulty is in following the trainer's instructions of picking up ' one up and one down ' ," when ' up ' and ' down ' are indistinguishable and unmeaningful. A correct result is obtained purely by accident, or as a result of a rhythmic movement of the wrist after being started off by the trainer at the correct place. The rhythmic movement would, of course, be useful only as long as the sizes of the threads were of even thickness : which is not often the case. This particular trainee, together with one other, was still unable to commence a twill weave for herself after twenty hours of training and practice.

At no time during the Experimental training were the trainees given a task which was perceptually difficult. This ensured two advantages : firstly, they did not encounter the phenomen—so apparent from general training experience and from the comments of the older trainees by the Exposure method—of stitches ' disappearing as you look at them '. Secondly, the Experimental trainee had complete understanding of the mending to be done. The Exposure group trainees, however, very soon lost confidence through lack of understanding. Their main concern seemed to be not so much their inability to mend correctly, but their inability to understand why it was incorrect. One trainee by this method at the end of the 20 hours was still unable to discuss whether her mending was correct or not.

It was noted that in the training of the younger menders magnifying lenses were somewhat unpopular, especially after the early stages of learning. The older group, on the contrary, appreciated them highly. It was agreed that they were an essential component of learning the perceptual skill but that after about twenty hours practice with them on weaves which were fully understood, trainees became able to find the correct place for stitching with the naked eye

and to maintain the effort for at least six inches of a mend without undue strain or confusion of pattern.

The comment of the women conducting the training by the Exposure method about the work of the trainee quoted earlier was " . . . you're learning it by what we call the hard way ". They were unable, however, to overcome the trainee's difficulties of understanding the twill by their continued demonstration and description and used the familiar phrase of encouragement " . . . it will come with experience ". The difficulties of learning to mend by descriptive and verbal methods were very apparent from the comments and performances of all the Exposure group trainees. In the face of severe perceptual difficulties, verbal description often served only as a further source of confusion. It was clear that much time was wasted in the use of terminology not understood and not remembered by the trainees. All the six women trained by the Exposure method said they found the instructresses difficult to follow : as is so often the case with experienced operatives they were found to be describing something completely familiar to themselves but which was not discernible to the beginner. With the training devices used by the Experimental method, this difficulty was overcome : neither description nor technical terms were used.

§ 5. The General Problem of Suitable Training Methods for Older People

The results of our three experiments suggest that older people, if taught by an appropriate method, are able to accomplish a task much more easily than they would otherwise. In each experiment we minimized the need for conscious memorization and, by so doing, several of the difficulties inherent in many of the current methods of training were overcome. A number of these difficulties have been summarized previously (Belbin 1955); while they may affect all trainees to a certain extent, many of them are proportionately greater for old than for young. Firstly, for example, it has been shown that older people find difficulty in translating data from one medium to another (Szafran 1953, 1955). The burden of translation from the verbal rules to motor skill was avoided in all our experimental methods of training. Secondly, the older person may be unable to perform a task because he finds proportionately greater difficulty in understanding instructions. Our experimental methods ensured that at all times the task to be performed—and to be learned while being performed—was never difficult enough to prevent comprehension or accurate performance. Thus, thirdly, errors were prevented during the early stages of training and did not have to be ' unlearnt ' later, a process which has been shown to be comparatively difficult for the older person (Kay 1951). In addition, by performing accurately in the early stages, the trainees were prevented from losing confidence in the job, a factor which often prevents successful learning by older people.

Not only were the older people able to learn an industrial task reasonably well by this ' activity ' type of method, but their performance compared very favourably with that of younger trainees. The comparison of this method with other methods in our former experiments with young trainees (Belbin *et al.* 1956, 1957) showed that it yielded somewhat better results than the traditional method, which makes considerable demands on memorization. It seems that

the preference for 'activity' learning, while of some importance amongst younger people, assumes a more enhanced role with increasing age.

This type of learning may, however, not be characteristic of all older people. In our experiments the subjects have been drawn from 'non-academic' groups, school leavers from secondary modern schools, and subjects who had ceased all formal learning since leaving school. There is evidence from previous experiments (Belbin 1956) to suggest that a difference exists between the preferred methods of learning by different people in the same age group: while University students showed preference for, and were superior to, artisan subjects in learning by memorizing, the artisan subjects did comparatively well in learning to *use* information. Further, in some pilot experiments conducted before the design of the present experiments was fully developed, a number of older subjects holding academic posts showed learning responses markedly at variance with those previously encountered in other older persons. They tried to superimpose conscious memorization on the activity method of learning and in consequence found our 'activity' learning task much more difficult than learning by memorizing.

Further work is clearly needed to establish the preferred methods of learning amongst older people in different walks of life. We may, however, tentatively advance the theory that learning is best accomplished when the method of teaching is appropriate to the learning activity which the individual has maintained over the years. If this is so, problems of whether training should be in part or in whole, with the aid of written or verbal instructions, with or without incentive, by memorizing or by activity, cannot be answered without reference to the previous experience of the individuals to be trained.

In relation to our present experiments, this type of experiential theory would imply that learning by memorizing is a skill that can itself be learned and maintained by continued exercise, and that the difficulties of memorization by certain older people are due to the skill having fallen into disuse. Where groups, such as older workers, mentally deficient persons or retarded children, have difficulty in learning particular tasks, we may find that it is not that a specific skill cannot be acquired at all, but rather that it could be learnt only if we found methods of teaching based on the previous learning experience of the people concerned. Individual differences in learning ability have not only received very little attention in research on industrial training, but have fallen completely outside the scope of psychological learning theory. It seems likely that while these differences are marked and assume considerable practical importance with regard to the training of older people, they are to be found, at least to some extent, during the years of early maturity. We believe that the evidence gives ground for the belief that this differentiation of preferred learning method should not only assume an important place in the study of ageing, but requires that learning theory and teaching methods should be recast in order to take it into account in the normal teaching of juveniles and adults.

The author is indebted to the Medical Research Council for a personal grant; to the Government Training Centre at Letchworth for supplying subjects for Experiment II; and to Mr. Frank Hill, Director of Training for the Wool (and Allied) Textile Employers' Council, for much cooperation and assistance.

On décrit trois expériences qui montrent des sujets d'un certain âge apprendre plus rapidement et complètement s'ils sont enseignés par la pratique plutôt que de mémoriser les instructions données. Dans les deux premières expériences le travail consistait en des triages de cartes, type laboratoire ; la troisième, en l'enseignement du raccommodage d'étoffes, laine peignée. Dans un article antérieur (Belbin *et al.* 1957) une méthode expérimentale d'enseignement a été comparée avec la méthode traditionnelle dite d' ' exposure ' ou ' sit-by-me '—' démonstration ' ou ' asseyez-vous près de moi '. La méthode expérimentale visait à l'élimination de la difficulté de perception qui, au cours des expériences antérieures limitait le succès de l'enseignement du raccommodage aux jeunes filles. On a même trouvé que cette méthode donnait de meilleurs résultats avec les sujets d'un certain âge qu'avec ceux quittant l'école.

Es werden drei Versuche beschrieben, welche zeigen, dass Personen mittleren Alters schneller und gründlicher lernen können, wenn sie die Arbeit wirklich ausführen, als wenn sie die Instruktionen auswendig lernen. In den ersten zwei Versuchen wurden Kartensortierungsarbeiten des Laboratoriumstyps verwendet. Der dritte Versuch bezog sich auf Ausbildung in dem Ausbessern von Kammgarnstoff. Ein in einem früheren Aufsatz (Belbin u.a., 1957) beschriebenes experimentelles Ausbildungsverfahren wird mit dem traditionellen ' Aussetzungs- ' oder ' sit-by-me '- Verfahren verglichen. Das experimentelle Verfahren zielte darauf ab, die Wahrnehmungsschwierigkeiten, die in früheren Versuchen die erfolgreiche Ausbildung junger Mädchen im Ausbesserungswerk beeinträchtigten, zu beseitigen. Es wurde gefunden, dass dieses Verfahren mit Subjekten mittleren Alters sogar bessere Ergebnisse als mit Schulabsolventen zeitigte.

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TRANSPORT BY MUSCLE POWER OVER SHORT DISTANCES

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The energy expenditure for piling up loads and shifting loads in a horizontal plane was measured. The best efficiency was found with loads lifted from a height of 0·5 to 1·0 m above ground, and the worst efficiency with loads lifted from ground level. It was much more efficient to transport the same total load in units of 15 to 28 kg instead of in units of 4 kg. In house-building the use of large bricks lifted from a height of 0·5 to 1·0 m above ground level instead of from the ground may save 80 per cent of manpower compared with the use of bricks of traditional size and type.

A normal man's capacity for transport by his own muscle power is limited to about 200 tons per day over a horizontal distance of 1 metre or about 50 tons per day over a vertical distance of 1 metre (Spitzer 1951). This daily output of energy uses about 2/- worth of food in nutrition. Since machinery is able to handle almost any load per day for one-fiftieth of this cost, long distance-transport by man power has disappeared in industrialized countries. What is left however, is transport by muscle power over short distances, from one vehicle to another, from a vehicle onto a pile and the reverse. Bricks and other stones for building, for example, are piled up in the factory, on the building grounds, and finally in the wall of the building itself. The energy expenditure for piling up stones of different weight and volume has been investigated systematically with the respirometer of the Max-Planck-Institute in Dortmund (Müller and Franz 1952). This investigation is representative for any other material in pieces of equal weight. Measurements of energy expenditure were taken on two normal men, under 36 different combinations of horizontal distance (0·5, 1·25 and 2·0 m), of starting-height (0·5 and 1·0 m) and finishing height (0·5, 1·0 and 1·5 m). The lightest stones had a weight of 4 kg with a volume of 0·002 m^3, the heaviest a weight of 28 kg with a volume of 0·03 m^3. The 4 kg-stones were taken with the right hand alone, the bigger stones with both hands.

The results are given in Fig. 1. It was assumed, that stones arrive by truck or rail and have to be piled up to a height of 1·50 m and a depth of 1 m. Three cases are shown separately in the figure. First: the stones were unloaded by tipping a cart load on the ground, from where they had to be piled up. Second: the material was taken from a lorry 0·5 m high. Third: it was taken from a platform 1 m high. The horizontal distance of transport varied between 0·5 and 2·0 m according to the changing distance between the place from which a stone was taken to its resting place in the pile. The weight of the pile was, in all cases, 1 long ton. Results for four different weights of the single stone to be handled are shown. The columns show the mean energy expenditure per pile of 1·5 m height, 1 m depth and of 1 long ton total weight.

Two results are evident:

(1) Taking the stones up from the ground increases the energy expenditure in the whole group by 50 per cent compared with a starting height of 0·5 or 1·0 m. That is due to the lowering and raising of the body.

(2) The piling up of bigger stones is, under all conditions, far more economical for a given total weight. That is due to the fact that a 28 kg stone involves one movement while seven movements are necessary to pile the same weight in 4 kg stones.

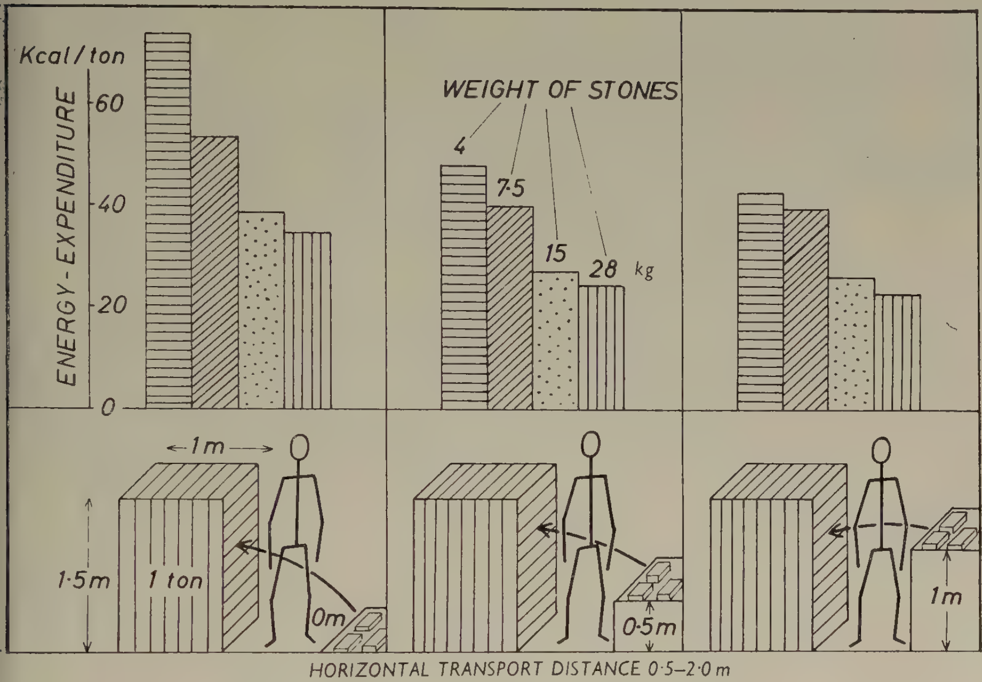

Figure 1. Energy expenditure in piling up.

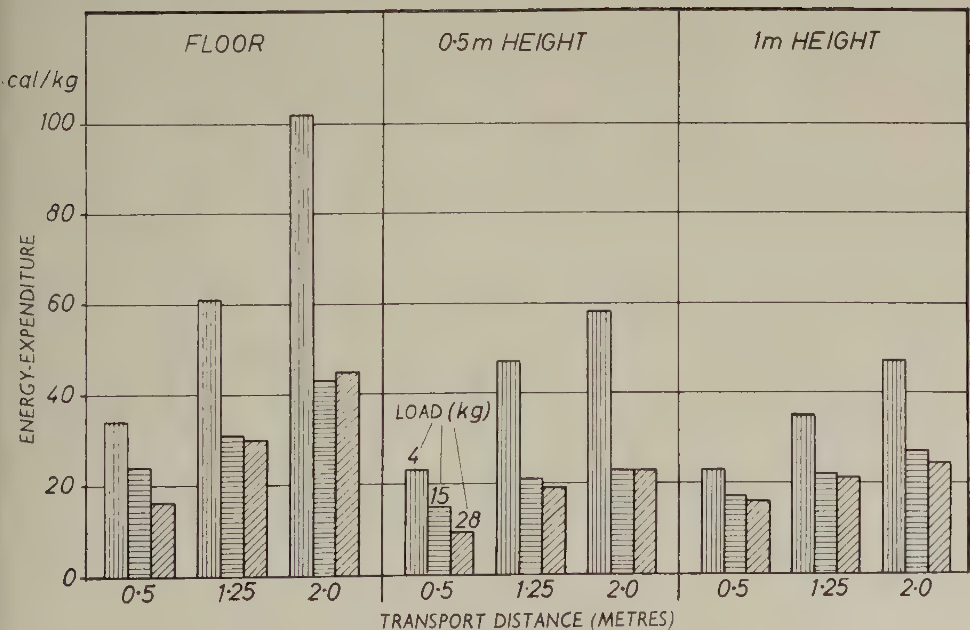

Figure 2. Energy expenditure in shifting weight in a horizontal plane.

The following practical rules are to be learnt from this: Never drop on the floor work pieces such as bricks which have to be piled up again. Deliver them at least to a height of 0·5 m. And further, pack the material in pieces of at least 15 kg. It should be understood also that the average horizontal distance of transport should be as short as possible. The results also show that it is possible for the daily output of a man to be doubled by halving the energy consumption for the same pile.

From our experiments we are also able to draw up rules for the transfer by hand of material at the same level. The results are condensed in Fig. 2. Here again transport at floor-height is relatively costly in energy, and handling the material in portions bigger than 15 kg is of great advantage.

Extremely favourable conditions are to be found in one special instance, viz. the horizontal transfer of 28 kg-pieces at 0·5 m height over a distance of 0·5 m. Under these conditions, arms, hand and load are swinging like a pendulum from the position of uptake to the point of set down, and back again. The movement needs practically no muscular contraction except for the grip of the fingers and the contractions of the muscles of the back in order to counterbalance the forward-pull of the load. It is obvious that only for that short distance and at that height can one make use of the favourable physical conditions for the swinging of the arms. Transporting the body on the level in walking is an equally economical process, whereby the centre of gravity follows a sinusoid type of curve.

Another way to transfer body parts and loads on the level without much muscular action would be achieved if limbs could be turned around an anatomically fixed vertical axis. Such an axis is partly given in our vertebral column. But too little horizontal distances can be covered in this way. For small parts one could lay the upper arm in a position where the elbow-joint axis stands vertically, and one could in that way transpose pieces over one yard or more by forearm movements with very little muscular energy. In all other cases the vertical axis has to be held in position by muscular contraction. The horizontally outstretched arm with a load in hand could turn around a vertical axis, but the movement would require muscle action for fixation. In most cases other joints have to be fixed as well in order to make hands and load follow the shortest way from the point of uptake to the point of laydown. This is the reason, why energy has to be spent by the body for transport at the same level.

Ideal conditions for building houses in Germany have resulted from the use of bigger and heavier building blocks. These save wall depth, and, on account of their cellular construction they have a low density and low heat conductivity. They save muscular power, since only one-third of the weight of normal bricks has to be transported for the same house. Furthermore these new and larger bricks have seven times the weight of normal bricks, but only half the energy expenditure is sufficient for the transport of the same total weight. Using all the physiological and technical knowledge on transport, one man is thus able to do as much building work as six men in former days (Schönefeld and Heising 1954).

On a mesuré la dépense d'énergie pendant l'entassement des charges et le déplacement des charges dans un plan horizontal. On a trouvé le meilleur rendement, quand les charges étaient soulevées d'une hauteur de 0,5–1,0 m au-dessus du sol, et le pire rendement avec les charges

soulevées du niveau du sol. Quand une charge donnée était transportée en unités de 15–28 kg, le rendement était plus grand que quand le poids de l'unité était de 4 kg. Dans la construction de maisons on peut, en employant de grandes briques soulevées d'une hauteur de 0,5–1,0 m au-dessus du sol au lieu du niveau du sol, économiser 80 pourcent de main-d'oeuvre en comparaison avec la manipulation des briques des dimensions et types traditionnels.

Der Energie umsatz für das Stapeln von Lasten und für das Verlagern von Lasten in horizontalen Ebenen wurde untersucht. Der beste Wirkungsgrad ergab sich beim Aufnehmen der Last in 0,5 bis 1,0 m Höhe, der schlechteste Wirkungsgrad beim Aufnehmen vom Boden. Es ist sehr viel ökonomischer, die gleiche Last in Stücken von 15 bis 28 kg statt in Stücken von 4 kg zu transportieren. Beim Hausbau können durch Verwendung grosser und schwerer Steine und durch Aufnehmen der Steine in 0,5 bis 1,0 m Höhe statt vom Boden 80 prozent Arbeitsstunden im Vergleich zur Verwendung normaler Ziegel eingespart werden.

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ELECTROMYOGRAPHIC INVESTIGATIONS DURING TYPEWRITING

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By recording electrical impulses from muscles during movements, it is possible to find the number of muscles taking part in the movement and when they are in activity and to estimate the force of contraction. The different factors which influence typewriting can therefore be studied by electromyography.

From these experiments it would appear that the most important factor is thorough practice on the typewriter. The person tested must also use favourable equipment (e.g. chair and table) and a satisfactory working position. The environment must be well lighted, not too cold, nor too noisy. The typist must use the highest preferred working speed, and take a short rest when tired.

When making a simple tapping movement, as in typewriting, much complicated ' work ' is performed by the central nervous system. All the afferent and efferent impulses, i.e. those from the brain as well as those from our surroundings, have to be coordinated before resulting in the ideal harmonious and effective movement. All such movements consist of many muscle contractions, each associated with electrical activity. By recording this electrical activity (EMG) it is possible to determine which muscles participate in the movement, when they are contracted, and, to a limited extent, the force of the contraction (Lundervold 1951).

Figure 1. Showing arrangement of experiment, with the subjects sitting at the typewriter in a screened room to facilitate electrical recording.

A. Potentiometer for recording finger movements.
B. Coupling-box.
C. and D. Amplifiers.
E. Film-camera.
F. Cathode-tube oscilloscope.
G. Electrode wires.
H. Partition wall (half-wall).
I. Dark-room lamp.
J. Ordinary lamp.
K. Suspension wires for the electrodes.

This method has been used in the examination of typists (Fig. 1). Both needle electrodes and surface electrodes were used. The electromyograms were recorded by means of a two-channel differential electromyograph and also with an eight-channel electroencephalograph. During these experiments

it was found that, if the slow tapping on the same key of a machine remained unchanged, the same motor unit potential could be followed for hours. The duration, amplitude and time of occurrence in the movement remained the same (Fig. 2).

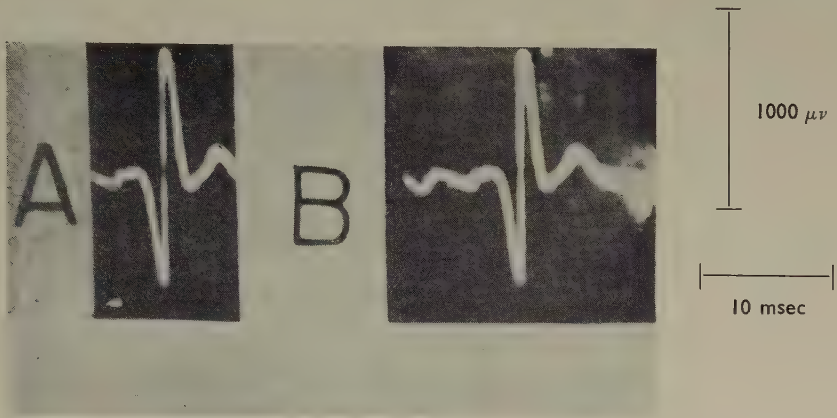

Figure 2. A and B ; The same motor unit potential recorded by needle-electrodes from the normal healthy pectoralis dext. on repeated striking of the same key with right index finger.

When the pace was slightly increased, two electric oscillations instead of one were recorded. When the key was more and more rapidly depressed, an increasing number of action potentials were recorded from the muscle at each stroke. With decreasing rapidity, on the other hand, the different electric oscillations gradually diminished in number, so that only the same motor unit potential, as seen at the beginning of the experiment, was recorded.

Besides being of decisive importance as regards the number of action potentials recorded in individual muscles, the rapidity also played an important role with respect to the number of muscles called into electric activity by striking a key. Generally speaking, it was found that the more rapid the speed of tapping, the larger was the number of muscles from which action potentials could be recorded (Fig. 3).

With small changes of speed a marked change could be observed in the number of action potentials. This means that a typist working at his preferred working speed is using relatively few muscles, and these are contracted only for a short period during the movement. He can, therefore, continue for a very long time at that speed. But if he just increases the speed very little he soon becomes tired and has to cease typing because of fatigue.

The influence of fatigue was also examined in the following manner. Investigations were usually begun with the subjects completely rested. They then repeatedly struck a key with the right index-finger. After a varying time, depending on the initial speed, the rapidity gradually diminished, so that the typist struck the key less often per second until quite unable to continue. The electromyograms obtained from the different muscles had, at the beginning, the same appearance as those previously described. It might have been expected that the duration and amplitude of the periods of electrical activity would diminish simultaneously with the rapidity as in rested persons. However, when the writer had to reduce the rate of striking as a result of fatigue, it

was found, on the contrary, that the duration and amplitude of the periods of electric activity steadily increased (Fig. 4). When there is a reduction of speed of movement, as a result of fatigue, there occurs not only an increasing number of action potentials, but also an increase in the number of muscles participating. The results were similar whether the action potentials were led off by means of needle or surface electrodes, and the findings were the same in all the muscles tested.

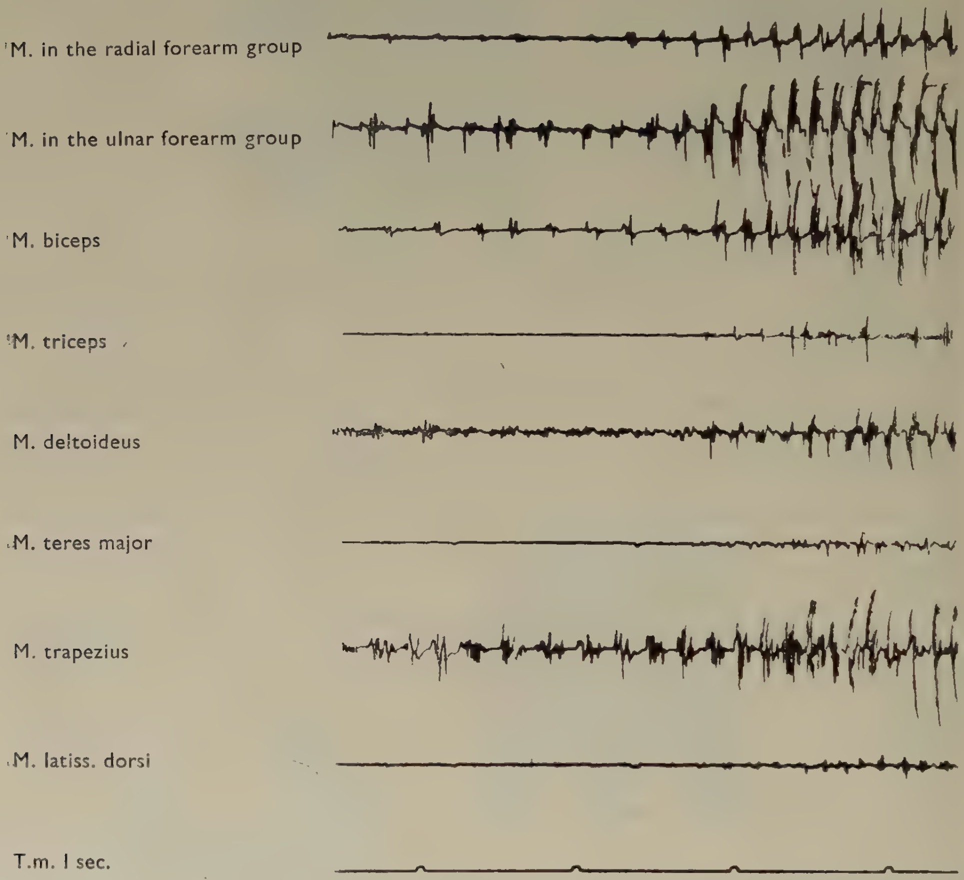

Figure 3. EMG recorded by skin-electrodes from eight different muscles simultaneously, ink-writer record, while the subject is repeatedly striking a key of the machine at increasing speed. T.m. Time marker, 1 sec.

Similar results were obtained from muscles which did not directly take part in the movement. For instance, in the muscles of the other limb with the arm resting in the lap, this electrical activity was strongest in the proximal muscles and occurred usually at the same time in the movement as it did in the homolateral muscles. These action potentials, however, called forth no visible movements in the extremity. The same results were obtained when the persons tested were typing at different speeds, and when they became tired.

Five women and ten men who had never previously written on a typewriter, were tested in exactly the same manner as previously adopted for the practised typists. They used their muscles in fundamentally the same manner as did the

skilled typists in corresponding exercises, but each individual muscle was contracted more forcibly and for a longer time. The difference in force of contraction between the unskilled writers and the skilled touch-operators was especially large. The untrained persons used far more muscular power in depressing the keys, while they also contracted more muscles, and each muscle more forcibly, when moving the arm from one position to another. The skilled touch-typists performed the corresponding movements with the use of fewer muscles, and with weaker contractions of those muscles which were in activity (Fig. 5).

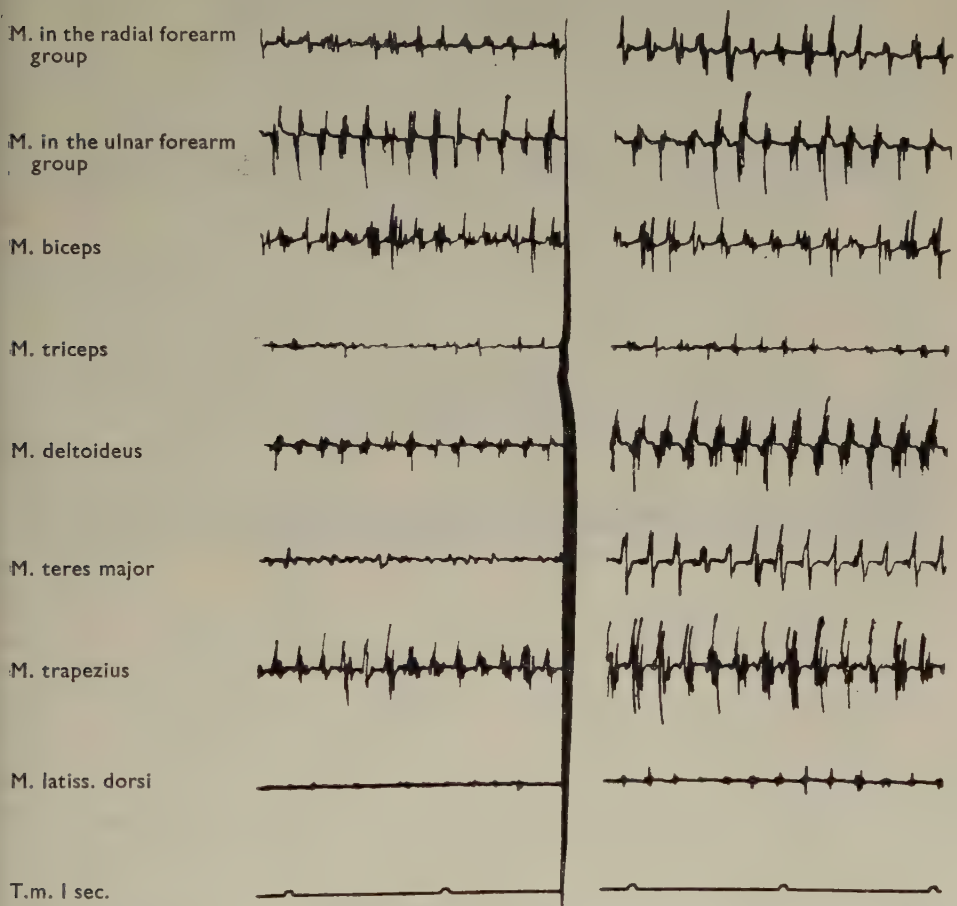

Figure 4. EMG recorded by skin-electrodes from eight different muscles simultaneously, ink-writer record, while the subject is repeatedly depressing the key at maximum speed. There is an interval of 2 minutes between the two records and 13 strokes have been recorded on each of them. T.m.=Time-marker, 1 sec.

In order to investigate very roughly whether temperature, noise or bad lighting had any influence on typewriting, the following experiments were carried out. The room temperature was altered from the normal 20°c to about 15°c (from 68°–59° Fahrenheit). In other experiments, the intensity of illuminations was reduced from 200 lux to about 10 lux. In the noise experiment, an apparatus was used which developed about 90 phons (decibels) of

noise. These investigations have shown that chilliness, loud noise and bad lighting may have the effect of causing the muscles to be contracted more vigorously than normal, and the number of muscles participating to be increased.

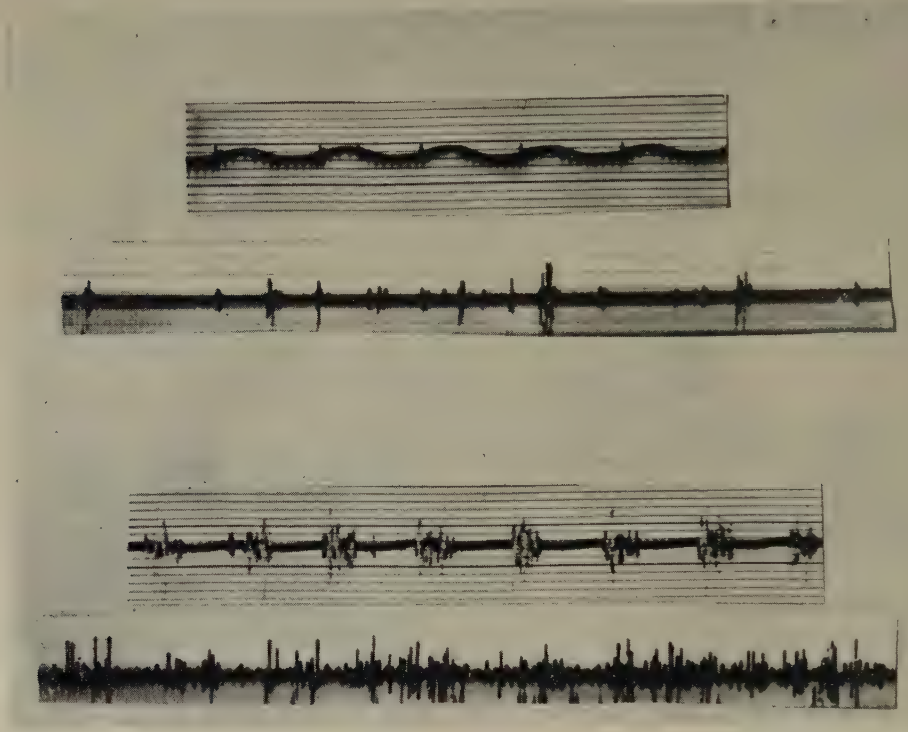

Figure 5. EMG from trapezius muscles, recorded by needle electrode. The two upper curves from a trained touch-typist ; 1st line, tapping one key, and 2nd line, ordinary typewriting. The two lower curves are from an untrained person doing the same exercise.

The influence of psychic factors on the electric activity of the muscles during typewriting, was more difficult to record with exactitude. A few experiments were carried out. It was found that constitutional factors played an important role, as it was the tense individuals who reacted most readily to psychic stimuli, both in a positive and negative direction. The more the writers concentrated their attention on the task, especially if they were sharply commanded to do so, the greater was the number of action potentials recorded. Conversely, there were found fewer muscle potentials when the attention was diverted from the task on which the writers were engaged. In the case of ordinary typewriting, this difference was especially perceptible in the electromyograms from the skilled typists.

In order to test this more accurately other more complex experiments were carried out more recently (Davis *et al.* 1957). The pulse and respiration rate as well as the sweat gland activity were then also recorded. All these factors showed increased activity when the muscle activity increased in the experiments previously mentioned. This was also so, but less marked, when a relaxed person was shown lantern slides periodically. When these experiments were

combined, the tapping movement and periodical looking at lantern slides, it was found that looking at the slides decreased the muscle activity as well as the pulse cycle time, fatigue being thereby postponed.

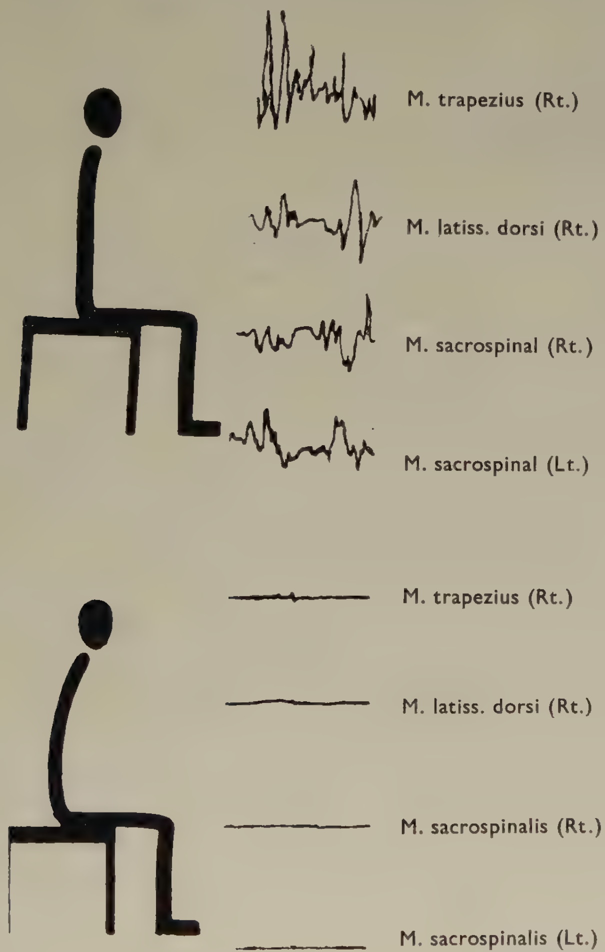

Figure 6. EMG recorded by skin-electrodes, ink-writer record, from the dorsal muscles of the trunk, while the subject of experiment is sitting :

A. In tense upright position.
B. In relaxed, well-balanced position.

Some experiments were also carried out in order to investigate the most suitable position for working. The subjects of experiment were allowed to adopt the position they themselves found most comfortable when sitting on a chair having a horizontal seat. The height of the seat above the floor was adjusted so that the typist sat with the entire sole of the foot planted on the floor and with the knee bent at a right-angle. Action potentials were then led off from different places in the trapezius, the latissimus dorsi, and the sacrospinalis muscles, usually on both sides. It was found that a number of the subjects could maintain their posture for a short time, without any action potentials being recorded from these muscles (Fig. 6).

In all subjects, after a longer or shorter period, a continuous series of motor unit potentials were recorded. The action potentials in the muscles appeared, at first, in bursts, which gradually increased in duration, so that the corresponding 'silent' periods between bursts diminished and finally disappeared. The results noted in different muscles were about the same.

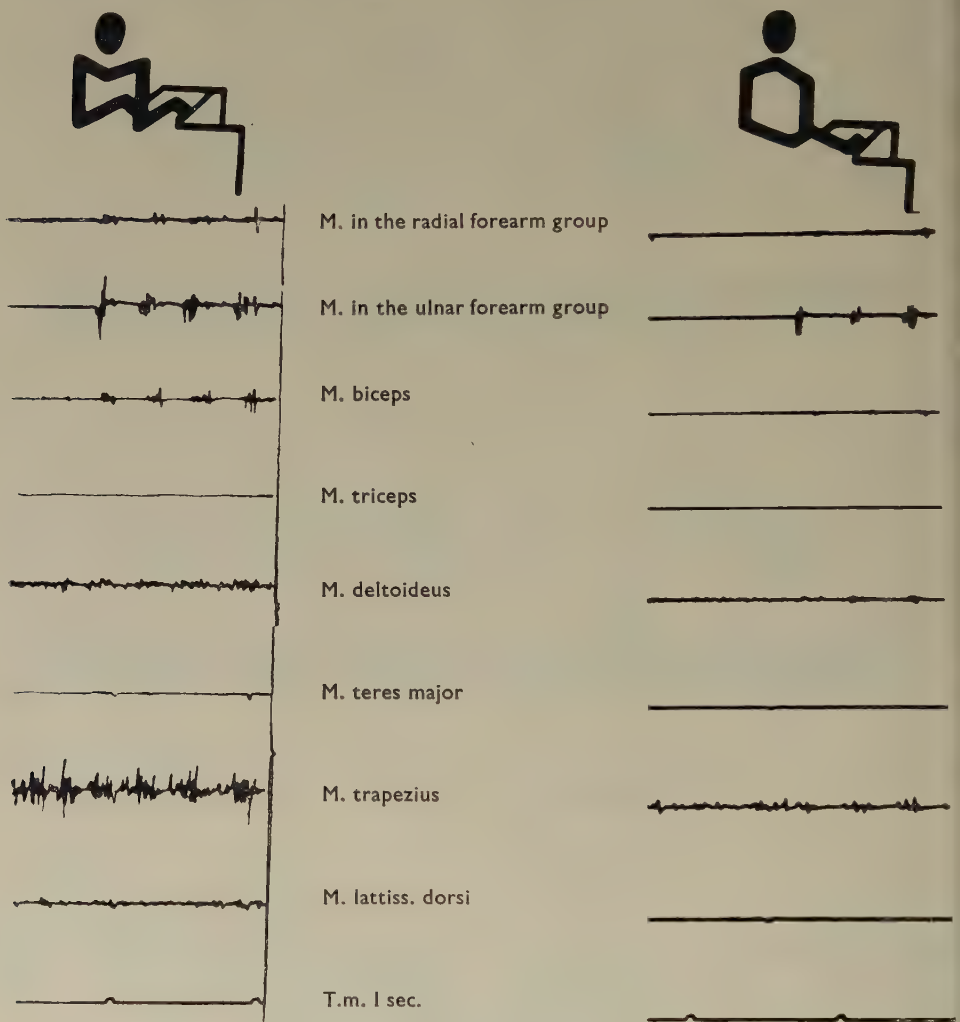

Figure 7. EMG recorded by skin-electrodes, ink-writer record.

A. The machine in high position. The subject raises the shoulders. Repeated striking of the same key of the machine.

B. Similar records obtained after the machine was lowered.

T.m.=Time-marker, 1 sec.

The length of time before the beginning of the continuous electrical activity in the dorsal muscles was decreased by the following procedures:

1. Raising the seat of the chair, so that the feet of the writer did not reach the floor.

2. Lowering the seat of the chair so that the right-angle formed by the knee became an acute angle.

3. Changing the slope of the seat so that the writer was on the point of slipping. Which way the seat was sloping was of no importance. If the seat was upholstered it was possible to change the slope somewhat more.
4. Crossing the knees.
5. Sitting in an erect ' military ' position.
6. Leaning forward.
7. Performing a task in sitting position.
8. When the person tested was tired.
9. When the chair was unsteady owing to easy movable castors on the legs.

The continuous muscular activity could be stopped for a longer or shorter period in the following ways.

1. When the writer changed his or her position on the horizontal seat.
2. When the angle formed by the knee was altered, provided that the entire sole of the foot, in the new position, rested on the floor.
3. By minor flections or extensions of the spinal column.
4. By use of the back-support, especially in the lumbar region.

The influence on the muscular activity during typewriting of a change in the height of the table and the position of the typewriter was also investigated (Fig. 7). The smallest number of action potentials were recorded when the person undergoing the experiment was sitting in a relaxed and well-balanced state of equilibrium, or was using a back rest. Moreover, the machine had to be placed squarely in front of the writer, and at a distance such that the upper arm could hang freely down when the person was typing.

En enregistrant les impulsions électriques obtenues des muscles pendant leurs mouvements, il est possible de trouver le nombre des muscles participant au mouvement et le temps de leur activité, ainsi que d'estimer la force de contraction. Par conséquent, il devient possible d'étudier au moyen d'un électromyographe les différents facteurs exerçant une influence dans la dactylographie.

Les résultats obtenus de ces expériences paraissent indiquer que le facteur le plus important c'est d'atteindre une pratique parfaite de dactylographie. La personne examinée doit aussi avoir à sa disposition un aménagement favorable (par exemple la chaise et la table) ainsi qu'être placée dans une position de travail satisfaisante. L'entourage doit être bien illuminé, pas trop froid et pas trop tumultueux. Le dactylographe doit écrire à la vitesse maxima préférée et avoir de brefs repos s'il est fatigué.

Die Registrierung der von Muskeln während deren Bewegung erzeugten elektrischen Impulse ermöglicht die Anzahl der an der Bewegung beteiligten Muskeln und die Zeit ihrer Aktivität zu bestimmen, sowie die Kontraktionskraft zu schätzen. Es ist demzufolge möglich, die verschiedenen das Maschinenschreiben beeinflussenden Faktoren mittels des Elektromygraphie-Verfahrens zu untersuchen.

Aus diesen Versuchen scheint es zu folgen, dass der wichtigste Faktor in der gründlichen Praxis des Maschinenschreibens besteht. Die untersuchte Person soll auch über eine günstige Ausstattung verfügen (z.B. Stuhl und Tisch), wobei die Arbeitsposition befriedigend sein soll. Die Umgebung soll gut beleuchtet, nicht zu kalt und nicht zu lärmvoll sein. Der Maschinenschreiber soll die höchste bevorzugte Arbeitsgeschwindigkeit anwenden, und, falls müde, kurze Rastperioden gewährt werden.

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MEASURING THE ORDER OF DIFFICULTY OF VISUAL-MOTOR TASKS

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It is sometimes necessary to find out whether one task is more difficult than another although both can normally be performed adequately. This paper describes a technique by which the relative difficulties of two tasks can be ascertained from data furnished by a subsidiary task, which has no adverse effect upon performance of the tasks under comparison.

§ 1. Introduction

We may wish to measure the order of difficulty of two or more designs for a piece of equipment, all of which are adequate under normal conditions because the operator is working well within his capacity even at the most difficult of them. If, however, the operator has to work under conditions of special difficulty or stress, one design may then prove to be more satisfactory than another. In the practical case it is sometimes either not possible or not desirable to test the operator under the actual adverse conditions concerned, and *a priori* calculations may be impossible.

In such a case a subsidiary task may be combined in turn with each of the tasks under comparison, and if performance with one primary task is more adversely affected than with another, the relative difficulties of the main tasks can be assessed. The theoretical basis of the technique is the assumption that there is a limit to the rate at which an operator can deal with information—in other words he has a limited 'channel capacity'. When the demands of primary and subsidiary tasks together exceed this limit, errors must occur.

The method is similar in general character to that used by Bahrick *et al.* (1954) and Broadbent (1956 a, b). The present experiment differs, however, from those done previously in two respects. Firstly, as regards the nature of the tasks: the primary task has been one of watching developing trends in a display rather than of reacting to signals of sudden onset. The secondary task involved judgements requiring the cumulation of data over a period of time rather than ones based on information immediately present. Secondly, an attempt was made to ensure that performance of the primary task was not affected by the subsidiary task, and that all effects of overloading the operator were shown by errors made in the subsidiary task. Previous experiments have left the subject free to make errors in either task, and the assessment of results has not always been easy because it has not been possible to say how far errors in the primary task were equivalent to those in the secondary.

The present experiment used as its main task two dial-watching operations in which the subject was required to respond each time the hand of a dial reached certain points. One task involved watching two dials, the other, six. The total *rate* of responses required was the same in both cases. Previous experiments with these tasks had shown that if the number of dials to be watched or the rate at which responses are required is high, an appreciable number of failures to respond or wrong responses occur. In the present case

the rate of signal presentation was so low that few errors were to be expected. We should nevertheless expect that performance at a subsidiary task combined with the six-dial primary task might be poorer than when it was combined with the two-dial.

§ 2. Apparatus

2.1. *Primary Dial-Watching Tasks*

The apparatus for these consisted of (*a*) two dials and (*b*) six dials together with release switches as described by Conrad (1955). Each dial had a black pointer 2 in. long which revolved in front of a white disc. The disc was 4·3 in. in diameter, and was divided into two by a vertical black line. After every half revolution the pointer stopped automatically at the vertical line (at 12 o'clock or 6 o'clock), unless or until the corresponding release switch was pressed. A stop constituted an error. It could be avoided by pressing the switch *before* the pointer reached the line, and holding it down until the pointer had crossed the line. Such a correct response scored one ' point '. If the pointer remained stopped, an additional error was counted every time the pointer would have made a sixth of a revolution if it had been running continuously.

In the two-dial condition the dials were mounted vertically side by side, about 6 ft in front of the subject and a little below eye level. The two corresponding control switches were fixed 3 in. apart to a table close to his left hand. Each switch lay opposite its dial. The dials required 1·54 and 1·23 responses per min respectively. A clock-type indicator which scored points minus errors was on the right of the dials. An alarm bell near the clock rang loudly for about 1 sec every time an error was made.

In the six-dial condition the dials were mounted in two rows of three, one row directly above the other, just below eye level. The six control switches were mounted 3 in. apart in two rows of three on an inclined plane surface. The row of switches for the upper dials was 3 in. further away from the subject, and also raised 1 in. above the row of switches for the lower dials. The top row of dials, in order from left to right, required an average of 0·36, 0·61 and 0·48 responses per min; the lower row required 0·54, 0·42 and 0·31 responses per min. The six dials thus required a total average of 2·72 responses per min, as compared with 2·77 for the two dials.

It was impressed upon the subject that errors must not occur under any circumstances. More than one switch could be held down at the same time only if necessary. The left hand was normally to be used, but when desired the right hand could be used also. The experimenter sat behind his subject. He noted the times, if any, at which the alarm bell rang, and also the probable causes of the errors.

2.2. *Subsidiary Auditory Task*

A magnetic-tape recorder delivered messages, one every 5 sec, at a comfortable loudness. The messages were supposed to resemble warnings which might be received in the engine room of a ship: an example is, " Gauge 47 shows temperature is too high ". Each message contained one two-digit number denoting a hypothetical gauge. The same two-digit number occurred in three out of a series of 10 consecutive messages. Three other two-digit

numbers were each common to the gauges mentioned in a pair of messages, and another (fifth) two digit number occurred in the remaining message of the series.

The numbers were taken from a table of random numbers, with the restriction that the same two-digit number did not occur in two consecutive series of messages. In the series the numbers were randomized systematically, with the restriction that the same two-digit number did not occur in two consecutive messages. After a series of 10 messages the subject heard the question: "From which gauge did most warnings come?" This was followed by a silent interval of about 5 sec, during which he had to record the number of the gauge which had been mentioned in three of the messages. The next series of 10 messages was then presented. A test contained 60 series, and took about an hour. A certain amount of variety was added to the task by systematic variations in the irrelevant information.

When the auditory task was performed alone, it was presented as a group test with pencils and paper. When it was combined with the dials, each subject worked individually with an electric adding machine to print his answers. Three reels of magnetic tape were prepared for the auditory task. They were similar except for the random numbers which they contained.

§ 3. Experimental Procedure

The experiment was preceded by two practices of about one hour each. There were three experimental conditions. Each took one hour, and was given on a different day. On one day a group of six subjects performed the auditory task by itself. On a day which preceded this for some subjects and followed it for others, the auditory task was combined with watching the two dials. On a third day the auditory task was combined with watching the six dials. Before beginning the combined tasks subjects were told: "The dials are your principal task. The alarm bell must never ring. Do your best on the listening. If you cannot do both tasks at any moment, it is the dials which must take priority." A balanced graeco-latin square design was used (Fisher, 1949 p. 78, Edwards 1951).

The 18 subjects were all naval ratings aged between 17 and 23 years. Their scores on intelligence test A.H.4 (Heim 1955) ranged from 57 to 94 with a median of 73.

3.1. *Procedure in a Control Experiment*

Eight additional but strictly comparable subjects performed the dial-watching tasks only. Four started with the two dials, and four with the six dials. The two tasks were performed on different days, and lasted one hour each. Before each period the subject practised for up to five minutes on the relevant condition.

§ 4. Results

The main results are given in Table 1, from which we may observe three points:

(i) The performances of the control subjects who carried out the dial-watching tasks without the auditory, did not differ significantly between the

two and the six dials. If one of the two dial-watching tasks was in fact more difficult than the other, the results of the control subjects did not show it conclusively. The tasks were therefore suitable ones to compare by the subsidiary-task technique.

Table 1. Mean Errors per 100 Responses

	Main Dial-Watching Task*	Subsidiary Auditory Task†
Experimental Subjects		
Auditory task only	—	20
Auditory task + 2 dials	0·49	28
Auditory task + 6 dials	1·64	39
Control Subjects		
2 dials only	0·66	—
6 dials only	1·03	—

The differences between the Experimental and Control Subjects were not significant at the 5 per cent level. Nor did the Control subjects show a significant difference between 2 and 6 dials.

* Auditory task + 2 dials significantly different from Auditory task + 6 dials ($P < 0{\cdot}002$).

† Auditory task + 2 dials significantly different from Auditory task only ($P < 0{\cdot}02$) and from Auditory task + 6 dials ($P < 0{\cdot}001$).

(ii) The results from the experimental subjects show that when dial-watching was combined with the auditory task, watching six dials gave significantly more errors in the auditory task than watching two dials. It may therefore be concluded that the six-dial task was more difficult than the two-dial task. This conclusion is in line with the results obtained by Conrad with higher rates of signal presentation and somewhat different experimental conditions. For example at 80 signals per min, he found that increasing the number of dials from two to three increased errors by a factor of four (Conrad 1951, Table 1). Increasing the number of dials from three to four almost doubled the errors again.

(iii) There was no significant difference on either dial-watching task between the experimental and control subjects. Thus adding the subsidiary task did not significantly increase the errors in the main dial-watching tasks.

The dial-watching tasks were performed significantly better in the later experimental periods than in the earlier ($P < 0{\cdot}01$); the auditory task showed only a small improvement with practice, which was not significant.

4.1. *Implications of the Results*

The results confirm those of previous experiments indicating that a subsidiary task can indeed reveal variation in the difficulty of different tasks all of which can be performed adequately.

Perhaps more striking is the illustration they give that a task in which very few overt responses are required and which is not really difficult in any ordinary sense of the word, can nevertheless load a man's capacity to an extent which leaves him little to spare for other activities. There is a widespread

tendency to regard as 'easy' and not requiring much 'effort' industrial tasks which call for little action by the operator. It is clear that absence of overt action does not necessarily indicate that a man's capacities are not being fully employed.

§ 5. Note on the Types of Error Made

5.1. *Dial-Watching Tasks*

The types of error made in the dial-watching tasks are set out in Table 2. The main point which is noticeable is the rise in the proportion of 'wrong switch' faults in the six-dial task. When the wrong release switch was pressed in the six-dial task, it was practically always the switch directly in front of or behind the correct switch. This suggests that the spatial relationship between the two rows of release switches and the two rows of dials was causing difficulty. The slightly-raised *back* row of switches corresponded to the *upper* row of dials. This is an interesting point in fitting controls to displays, upon which further experimental evidence might well be obtained.

Table 2. Types of Error made on Dial-Watching Tasks. Means per 100 Responses

	Wrong Switch*	Late Response†	Minor Fault‡
Experimental Subjects			
Auditory task + 2 dials	0·03	0·36	0·10
Auditory task + 6 dials	0·56	0·74	0·34
Control Subjects			
2 dials only	0	0·59	0·07
6 dials only	0·22	0·52	0·29

None of the differences between the Experimental and Control subjects is significant on the 5 per cent level. The control subjects showed no significant differences between 2 and 6 dials.

* Auditory task + 2 dials significantly different from Auditory task + 6 dials ($P<0{\cdot}01$).

† Auditory task + 2 dials significantly different from Auditory task + 6 dials ($P<0{\cdot}05$).

‡ Minor faults were due to such errors as not pressing switches hard enough or to finger slipping on a switch.

5.2. *Auditory Task*

In the auditory task the required two-digit number was more easily identified if it came in the first or last message of the series ($P<0{\cdot}05$), and also if it came in alternate messages (e.g. the second, fourth and sixth) ($P<0{\cdot}05$). Half the errors consisted in reporting an incorrect two-digit number which was present in the series, and which had the same first or second digit as one of the other four two-digit numbers in the series. For example, if 58 and 53 both appeared not more than twice in the same series, the subject might incorrectly report one of them. The two-digit number reported erroneously tended to be the one in the last message of a series ($P<0{\cdot}001$). It can be shown mathematically that this tendency probably accounts for the relatively high proportion of correctly-recorded numbers which occurred in the last message. About 15 per cent of the errors were two-digit numbers which did not occur in

the particular series. Two-thirds of these errors could have been due to confusing two of the two-digit numbers which were in that series. It can be shown mathematically that if the subject had been guessing at random, a proportion of only one in five would be expected. About 10 per cent of the errors were failures to respond.

The experiment was carried out at the suggestion of Dr. N. H. Mackworth. Dr. R. Conrad very kindly loaned his experimental room and apparatus. Dr. H. M. Bowen gave advice on the design of the listening task. Mr. M. Stone advised on statistical methods, and Dr. H. Banister helped with the reporting. The subjects were supplied by the Royal Navy. Financial support from the Medical Research Council is also gratefully acknowledged.

Il est parfois nécessaire de trouver si un travail est plus difficile qu'un autre, nonobstant le fait que normalement tous les deux peuvent être exécutés d'une manière satisfaisante. On décrit dans cet article une technique qui permet d'évaluer les difficultés relatives de deux travaux au moyen des résultats obtenus d'un travail auxiliaire, n'exerçant d'influence négative sur l'exécution des travaux comparés.

Es ist manchmals nötig festzustellen, ob eine Arbeit schwieriger als eine andere ist, obwohl normalerweise beide hinreichend gut ausgeführt werden können. Es wird in dem vorliegenden Aufsatz eine Technik beschrieben, die es ermöglicht, die relativen Schwierigkeiten von zwei Arbeiten auf Grund der mittels einer Hilfsarbeit erhaltenen Daten zu bestimmen, wobei die Hilfsarbeit auf die Ausführung der verglichenen Arbeiten keinen beeinträchtigenden Einfluss hat.

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MEASUREMENTS OF VISIBILITY FROM THE DRIVING SEAT OF MOTOR VEHICLES

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Even in daylight in clear conditions the driver's visibility, both forward and rearward, is restricted by the structure of the vehicle. Important sections of the view can be obscured ; thus a windscreen pillar can obscure a pedestrian or cyclist until it is too late to avoid an accident. A given vehicle has certain visibility characteristics. The work described in this paper is the measurement of these characteristics for a range of vehicles.

The method of measurement is based on an American technique in which two lamps are positioned to correspond with the eyes of an average driver. The visibility is measured by means of the shadows cast by body pillars, bonnet, etc., and by the light reflected rearwards by the mirror. Both forward and rearward visible areas can be interpreted as plans of visible areas on the ground. In the choice of eye position, consideration was given to the position of the eyes relative to the seat and to the position of the seat in its travel. The seat is positioned with reference to the accelerator pedal at a distance determined from measurements of a small sample of drivers in different cars and of owner-drivers and their cars. For private cars the ' eyes ' are placed on a vertical tangent to the seat squab at a fixed height above the undeflected seat, this position being based on measurements made by the General Motors Corporation of America. For commerical vehicles the same eye height is used, but a fore and aft correction is applied for variations of the angle of the seat-back to the vertical, which can be large in this class of vehicle. This correction factor was obtained from the averages of measurements on 25 drivers, using a seat in which the angle of the back could be varied. This specification of eye position is a very simple one, and was adopted to avoid the use of dummies and because it was considered to be adequate for the comparisons needed. In use it has occasionally given misleading results, e.g. when large variations of seat softness have been encountered.

A wide range of cars and commercial vehicles has been examined. A typical result from one of these is given. The chief points of comparisons between vehicles are the extent of the forward obscuration by the windscreen pillars and bonnet and the vertical and horizontal angles of rearward vision. In cars these factors are affected by styling. In particular, with low roof-lines, the eye level tends to come high in the car, where the pillar thickens to meet the roof, resulting in large obscurations. The high eye level also restricts the positioning of internal mirrors in that it is difficult to obtain good rearward visibility without causing undue forward obscuration.

§ 1. The Problem

The driver of a vehicle has certain restrictions placed on his view of the road. In fog his view may be only a few feet in any direction, while at night his field of view is largely restricted to the beam of his headlight and to less than this when dazzled by on-coming traffic. Even in broad daylight, however, his view is restricted by the structure of the vehicle itself, e.g. by the bonnet and windscreen pillars for forward vision, and the size of the mirror or rear window for rearward vision. No case need be made out for the necessity of minimum restriction of rearward vision. If rearward vision is difficult then there is considerable risk of causing accidents by turning across the path of another vehicle, either on the near or off-side. The effect of body structure on forward vision may seem less serious. In terms of responsibility for accidents doubtless these obscurations do not rate very highly, but this should

not deter designers from giving careful consideration to the subject, since any measure likely to decrease accidents should be pursued, and any style changes likely to adversely affect the accident rate should be recognized and resisted.

Two situations in which obscuration of forward vision are important are indicated in Fig. 1. Only the nearside pillar obscuration is shown, but it will be seen that this can cover, for example, the view at a road junction, of a motor cyclist about to cross the car's track. As the two vehicles approach there may be a tendency for the motor cyclist to stay in the car's blind spot and this increases the likelihood of an accident. Complete continuation of obscuration is unlikely to occur, but this is not necessary to ensure an accident. Once the vehicles have approached to within a certain distance it may be too late for avoiding action to be taken. The other example is of the pillar obscuring a pedestrian. If a pedestrian starts to cross the road, when thus obscured, the driver will not be aware of this at once, and when he does see the pedestrian it may be too late to avoid hitting him.

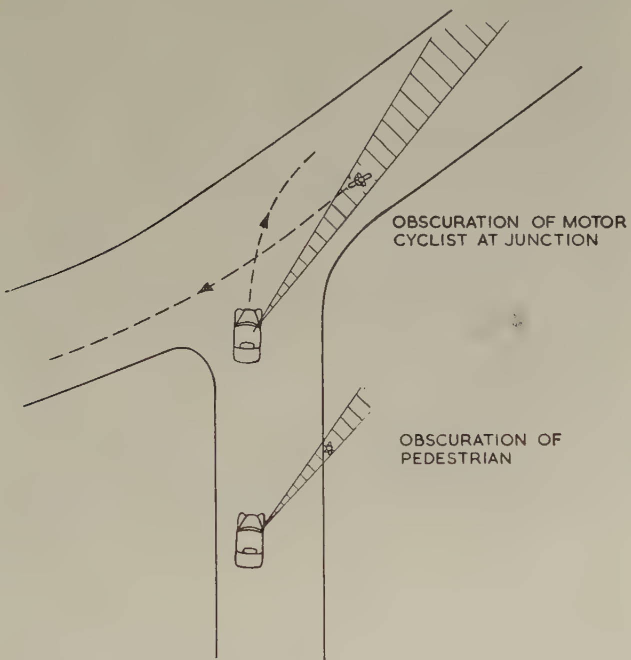

Figure 1. Obscuration of another vehicle or pedestrian by a windscreen pillar.

The amounts and position of the obscuration of vision, both forward and rearward, varies with the design of the car. Thus, a given car may be said to possess certain visibility characteristics. It is the measurement and assessment of these characteristics with which this paper is concerned. This work was carried out at the Motor Industry Research Association at the request of the Society of Motor Manufacturer and Traders. The initial object was to develop a method of measuring the visibility from a vehicle and the final object was to suggest recommendations concerning the minimum visibility requirements desirable for new vehicles. Several simplifying limitations

were adopted in the methods of measurement, chiefly because the problem was not concerned so much with absolute measurements as with comparing cars. The chief simplification of method resulting from this approach was to base the measurements on an average driver and a fixed eye position. The latter, although based on measurements of actual drivers, is specified in relation to the undeflected seat, so that the use of dummies could be avoided.

§ 2. Method of Measurement

The method of measurement used was based on an American rig, and consisted of placing two electric lamps at the positions of an average driver's eyes and measuring the areas visible to the driver by means of the illumination and shadows cast by these lamps on suitably placed screens. Figure 2 shows

Figure 2. Lamps in position.

a car with the lamps in position, and a plan of the rig is shown in Fig. 3. The car is positioned facing a hemi-cylindrical screen so that the mid-point between the ' eyes ' is on the axis of the screen. From a knowledge of the height of the eyes, points on the screen can be interpreted in terms of positions on the ground. By projection of points on the boundaries of the shadows cast by the pillars, bonnet and other fittings, a ground plan of the areas visible to the driver can be drawn. Also, by the light reflected from the internal mirror on screens placed behind the car, ground plans can be obtained for the driver's rearward vision. The identification of the virtual point scources of light, from which to calculate the ground plan of rearward vision, is not easy, and a simpler method of deriving the ground plan is to take measurements of the illuminated area on a plane screen in two positions. A ground plan of vision can be

calculated by simple projection of corresponding points on the boundaries of the illuminated areas for each position of the screen. The hemi-cylindrical screen in use for recording forward vision is shown in Fig. 4.

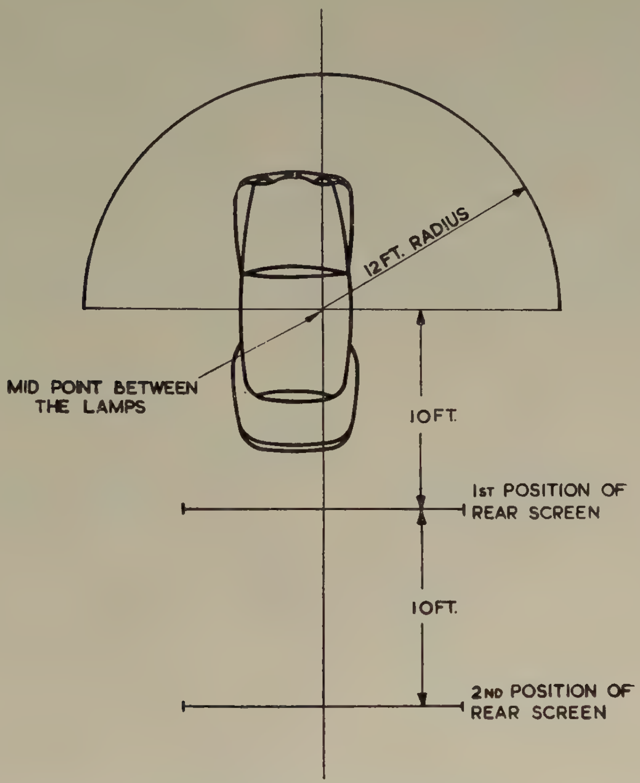

Figure 3. Plan of visibility set-up.

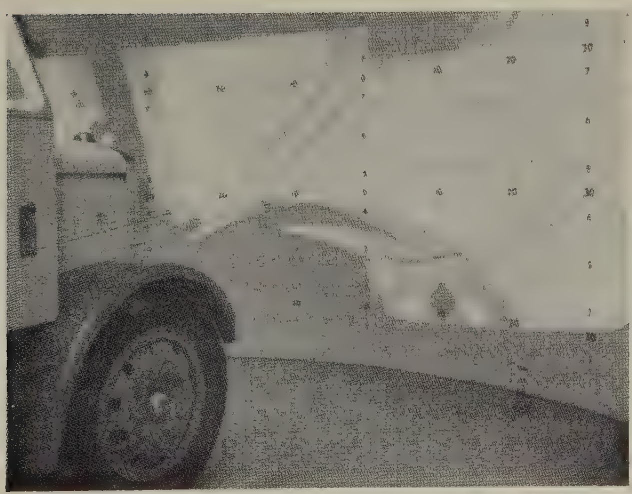

Figure 4. Forward screen in use.

In this method, the chief problem is to determine where to put the lamps in order that they should correspond to the position of the average driver's eyes. This problem divides into two parts : firstly, where to place the eyes in relation to the seat ; and, secondly, where to position the seat in relation to the rest of the vehicle.

When a driver sits in a car he adjusts the seat so that he can reach the controls. The most important of these in normal driving are : the steering wheel and gear lever, to be reached with the hands, and the accelerator, brake and clutch pedals, to be reached with the feet. The accelerator pedal is probably the most important in affecting the choice of seat position, since it is in constant use and its small size limits the possibility of changing or varying the leg position during driving. In standardizing the procedure it is simplest if only one set of conditions is taken into account. Thus it was decided to fix the seat relative to only one control ; because of its unique characteristics, the accelerator pedal was chosen.

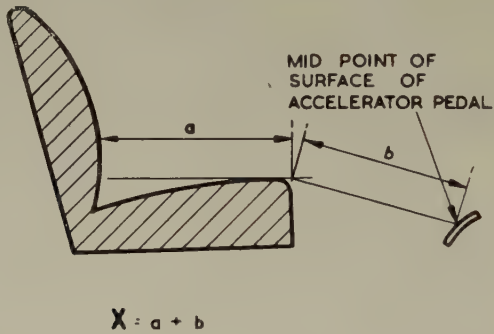

Figure 5. Showing measurement of seat position relative to accelator pedal.

To fix the seat position, the distance from the back of the seat to the accelerator pedal was measured, as shown in Fig. 5. To determine a suitable value for this dimension, measurements were made of drivers in different cars and of owner-drivers in their own cars. Eight drivers whose average height and weight correspond fairly closely to the population average were asked to sit in turn in six cars and to adjust the seat position. The selected seat to accelerator pedal distances were then measured, yielding a figure of 37 in. The limitation of this method was that the test subjects had only a few minutes in each car in which to select the most comfortable position, and there is a possibility that the position thus chosen would not be the most comfortable for long periods of driving. A check on this point was made by measurements of the cars of nine owner-drivers, who were assumed to have adjusted the seats in their cars to the most comfortable position. For this sample an average seat to accelerator pedal distance of 36·7 in. was found.

Less control was possible over the choice of the sample of owner-drivers and the average height and leg length were slightly larger than those for the population means. The correlation between leg-length and seat-to-accelerator-pedal distance was not, however, good enough with this sample of drivers to provide a basis for a correction ; it is certain that the figure is on the high side.

Since it was not necessary to fix this distance to nearer than $\frac{1}{2}$ in. for the measurements of visibility, a seat-to-accelerator-pedal distance of $36\frac{1}{2}$ in. was finally chosen. It was of interest in these measurements to compare the seat-to-accelerator figure for the average driver with figures obtained by measurement on cars with the seats in the mid-position of travel. It was found that of 15 cars less than half had seat mid-positions within an inch of the figure corresponding to an average driver.

The eye position chosen relative to the seat varies with the class of vehicle and depends on such factors as the seat softness and the angle of the seat back to the vertical. If the seat is soft the driver sinks into it, while if the slope of the back to the vertical increases the eyes move rearward relative to the base of the seat. In private cars the variation of seat back angle is generally such that it is possible to ignore it, and the eye position chosen is the same as that used by General Motors. The 'eyes' are placed at a fixed height above the undeflected seat on a vertical tangent to the seat squab (Fig. 6).

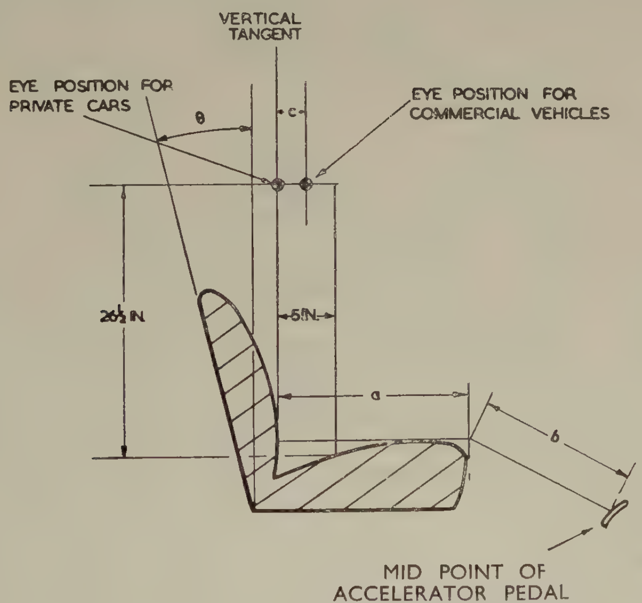

Figure 6. Showing standard eye positions.

In the case of commercial vehicles the variation of seat-back angle to be expected is greater. In some of the more austere lorries the seat back is nearly upright, whereas with the smaller vans the type of seat fitted is the same as used in private cars, and may have seat-back angles of 20 deg. or more from the vertical. The effect of such large changes of angle were investigated by measurements with a sample of 25 drivers and a seat of which the angle of the back to the vertical could be varied. Curves were obtained giving the variation of eye position with seat back angle and these showed that the change of vertical position was negligible, but the fore and aft change was sufficient to be taken into account. The final eye position chosen for commercial vehicles is also shown in Fig. 6; it is at the same height as that

for private cars, but a fore-and-aft correction has been made based on the measurements referred to above. This correction is given in Fig. 7 and is an average for the sample of drivers used. The range of scatter of individual results was such that 90 per cent came within $\pm 2{\cdot}25$ in. of the mean.

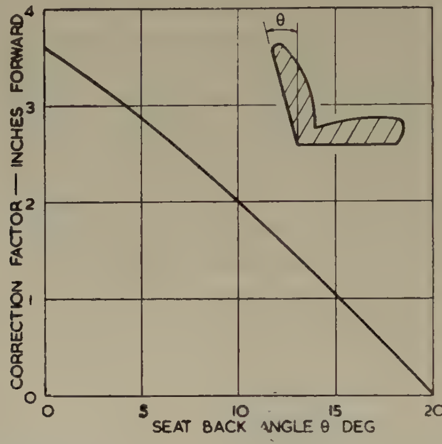

Figure 7. Horizontal correction factor for eye position used for commercial vehicles.

The chief limitations of these eye positions are that they assume a constant seat-softness, and, for private cars, a constant seat-back angle. In practice both of these vary, but it was considered that the simplicity of the method outweighed its disadvantages. In the examination of about 40 vehicles the method has given obviously misleading results in only three cases. A further condition of measurement is that no account is taken of rotation of the head. This is because the method is essentially for use in comparing vehicles and turning the head will give similar effects in all vehicles. Figure 6 illustrates the vertical and fore-and-aft positioning of the eyes : the transverse position varied with the type of seat. With bench and flat-backed single seats the driver normally sits immediately behind the steering wheel, and the eyes were therefore positioned to be in line with the centre of the wheel. Exceptions to this occur in commercial vehicles where bucket type seats are sometimes offset from the steering wheel. In these vehicles it is physically impossible to sit immediately behind the wheel, and the transverse position of the eyes has been taken at the centre of the seat.

§ 3. Results

A typical forward visibility result is given in Fig. 8. The upper diagram is a copy of the forward screen shadows and shows the areas visible to each ‘ eye ’ separately. Those areas which are double cross hatched are completely obscured for both eyes. The arcs on the windscreen show the areas cleared by the wipers (obtained by coating the windscreen with metal polish and then removing that over the swept areas with the wipers). The lower diagram in Fig. 8 is a ground plan calculated from this forward screen pattern. The areas of complete obscuration are hatched and the broken lines indicate the limits of visibility through the windscreen wiper areas,

The chief points of comparison between cars are the extent of obscuration by (i) the windscreen pillars and (ii) the bonnet. With modern styling the latter is usually quite small, but the pillar obscuration can be quite large. Apart from the width of the pillar itself, the level of the eyes relative to the pillar is of great importance. There is a tendency in the styling of modern cars for roof lines to be low and, if corresponding reductions are not made in the level of the seat, the eye level may come where the pillar thickens to meet the roof. At the top of the pillar the rate of increase of width with height is large, and a driver whose sitting height is above average is at a particular disadvantage.

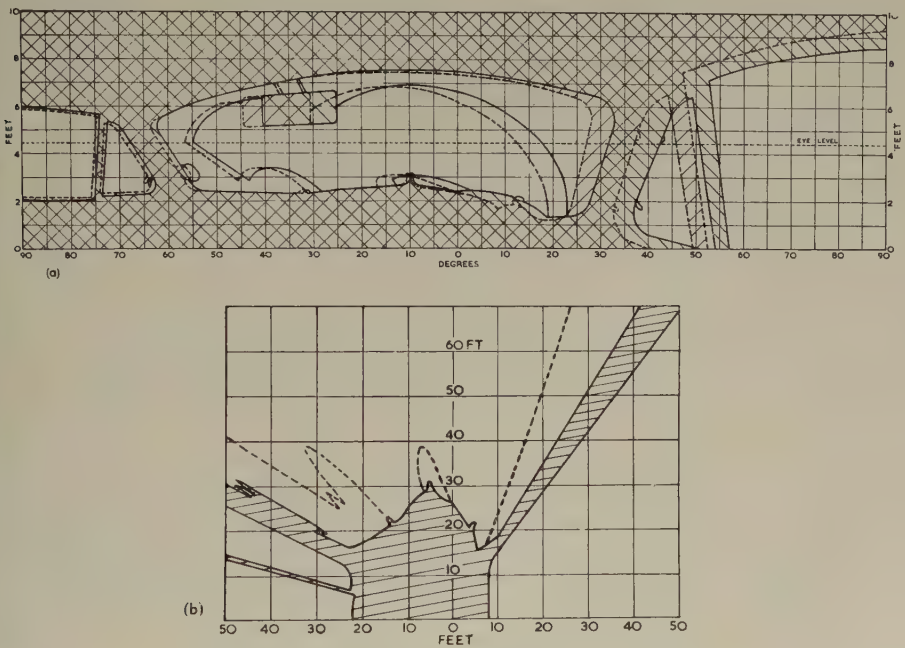

Figure 8. Typical forward visibility results.
(*a*) Forward screen diagram.
(*b*) Ground plan for near forward vision.

A typical rearward vision ground plan is shown in Fig. 9. In this, vision for both the loaded and unloaded vehicle is given. Passenger load has little effect on forward vision, but on rearward vision it is sometimes very marked. This is again a characteristic of low roof-styling but coupled with soft springing. A low roof-line entails a low position for the top of the rear window and soft springing results in the car tipping rearwards when loaded. Under no load conditions it is sometimes difficult to place the mirror to give an adequate vertical field of rearward vision. When the car is loaded this difficulty is increased. If rearward vision were the only problem, the mirror could always be lowered to give a satisfactory vertical angle of view, but this method of improvement is limited in practice, because it often results in an intolerable forward obscuration by the mirror itself.

These examples show the points that are looked for in comparing the visibility characteristics of different vehicles and models. Manufacturers can see how past, present and future models compare with one another, and

how their own models compare with those of competitors. To provide a more fixed basis of comparison, recommendations have been prepared incorporating suggested minimum visibility requirements for both private cars and commercial vehicles. These are based on safety considerations where possible. Work carried out by the Road Research Laboratory on the effect of the horizontal angle of rearward vision on the appreciation of overtaking vehicles has provided experimental data on rearward visibility. For forward vision however, no data of this type exist. In regard to pillar obscuration it would probably be ideal if the pillar thickness were no more than to

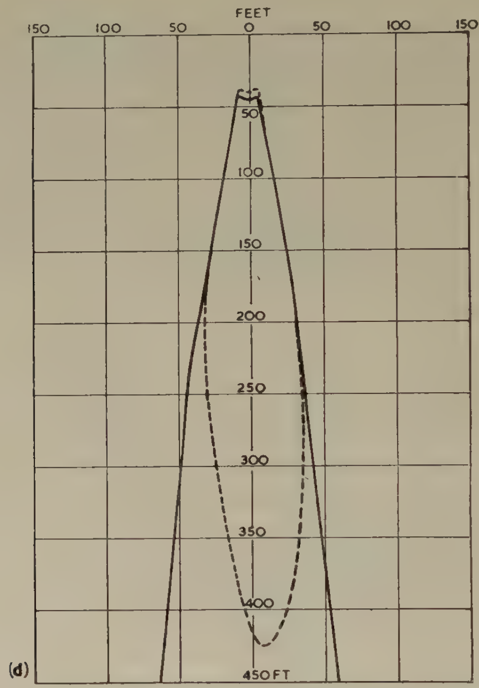

Figure 9. Typical ground plan of rearward visibility.

correspond with the eye spacing, so that, with binocular vision, the effective obscuration would be negligible. In practice, expense considerations do not permit this. Some cars more nearly approach the ideal than others and the suggested minimum requirements have been based on the best of these. Similar considerations were applied in suggesting requirements for near forward vision and windscreen wiper clearances.

In conclusion it should be emphasized that this work is not regarded as providing standards of visibility, but as providing a recommended code of practice. The type of measurement is not sufficiently developed to serve as a basis for a rigid system of requirements, nor is this desirable. At present one of the most useful advances would be to gain an increased status for the visibility aspects of design. It is hoped, for example, that more attention may be given by manufacturers to the effect of styling and seating on visibility, and especially in regard to the provision of more suitable vertical and horizontal seat adjustments to allow for variations of dimensions of drivers.

The author wishes to thank the Director and Council of M.I.R.A. for permission to publish this work.

Même à la lumière du jour et au temps clair, la visibilité du chauffeur, en avant ou en arrière, est limitée par la structure del a voiture. Des parties importantes du champ de vue peuvent être cachées ; c'est ainsi que la colonne d'un pare-brise peut masquer un piéton ou un cycliste, jusqu'à ce qu'il soit trop tard pour prévenir un accident. Chaque voiture possède certaines caractéristiques de visibilité. Le présent article décrit la mesure de ces caractéristiques pour une série de voitures.

La méthode de mesure se base sur une technique américaine dans laquelle les positions de deux lampes employées correspondent aux positions des yeux d'un chauffeur moyen. La visibilité est mesurée au moyen des ombres jetées par les colonnes de la carrosserie, le capot etc., et au moyen de la lumière reflétée en arrière par le miroir. Les surfaces visibles d'avant et d'arrière peuvent être interprétées comme les projections des surfaces visibles sur le sol. En choisissant la position des yeux, on a pris en considération la position des yeux en relation au siège et à la position du siège pendant son mouvement. La distance entre le siège et la pédale d'accélération est déterminée par des mesures conduites avec un petit nombre de chauffeurs dans de différentes voitures ainsi que de chauffeurs-propriétaires et leurs voitures. En cas de voitures privées, les ' yeux ' sont placés sur une tangente verticale au coussin de siège, à une hauteur fixée au-dessus du siège non-dévié : cette position se base sur les mesures faites par la General Motors Corporation of America. La même hauteur des yeux est employée pour les voitures de commerce, mais on y emploie une correction d'avant et d'arrière pour les variations de l'angle entre les dos du siège et la direction verticale, qui peuvent être bien grandes pour les voitures de cette catégorie. Ce coefficient de correction a été obtenu das valeurs moyennes des mesures obtenues avec 25 chauffeurs, en employant un siège où l'angle du dos pouvait être varié. Cette description de la position des yeux est très simple ; on l'a adopté pour éviter l'emploi des mannéquins et par ce qu'elle était regardée comme adéquate pour les comparaisons nécessaires. Néanmoins, elle a parfois donné en pratique des résultats trompeurs, par exemple en cas de grandes variations de la mollesse du siège de la voiture.

On a examiné une grande série de voitures privées et de commerce, et l'on donne un résultat type, obtenu avec une de ces voitures. Les points principaux de comparaison entre les voitures sont : le degré du ' masquage ' en avant par les colonnes du pare-brise et le capot, et l'angle vertical et horizontal de la vision d'arrière. Ces facteurs dépendent de la construction des voitures. Tout spécialement, quand les lignes de toit sont basses, l'oeil dans la voiture se trouve à un niveau où la colonne s'épaissit à la proximité du toit, ce qui produit de grandes obscurcissements. Le haut niveau de l'oeil limite de même le choix des positions des miroirs intérieurs, car il devient difficile d'obtenir une bonne visibilité d'arrière sans causer une obscurcissement d'avant exagérée.

Sogar im Tageslicht und wenn das Wetter klar ist, wird das Sehvermögen des Kraftwagenführers, sowohl nach vorne als rückwärts gerichtet, durch den Bau des Wagens begrenzt. Wichtige Teile des Gesichtsfeldes können verdeckt werden ; so kann die Säule der Windschutzscheibe einen Fussgänger oder Radfahrer verdecken bis zu einem Augenblick, wo es zu spät ist, den Unfall zu verhüten. Ein jeder Wagen hat gewisse Kennzeichen des Gesichtsfeldes. Die im vorliegenden Aufsatz beschriebene Arbeit betrifft die Messung dieser Kennzeichen für eine Reihe von Kraftwagentypen.

Das Messverfahren beruht auf einer amerikanischen Technik, in welcher zwei Lampen so angeordnet sind, dass ihre Lagen denen der Augen eines Durchschnittswagenführers entspricht. Das Gesichtsfeld wird mittels der durch Karosseriesäulen, Motorhaube usw. geworfenen Schatten gemessen, sowie mittels des von dem Spiegel rückwärts reflektierten Lichtes. Die vorne und rückwärts sichtbaren Flächen können als Projektionen der sichtbaren Flächen auf den Boden aufgefasst werden. Was die Wahl der Augenlage anbetrifft, so wurde diese Lage in Bezug auf den Sitz und dessen Lage während der Fahrt in Erwägung gezogen. Der Abstand zwischen dem Sitz und dem Beschleunigungs fusshebel wurde aus der mit einer kleinen Anzahl von Wagenführern in verschiedenen Wagentypen sowie von Inhaber-Führern in deren Wagen ausgeführten Messungen bestimmt. Für Privatwagen wurden die ' Augen ' auf der senkrechten Tangente zum Polsterkissen auf einer bestimmten Höhe über dem nichtabgelenkten Sitz angeordnet ; diese Lage beruht auf den von der Fa. General Motors Corporation of America ausgeführten Messungen. Dieselbe Augenhöhe wird für kommerzielle Wagen benutzt, doch wendet man in diesem Falle eine Vorwärts- und Rückwärtskorrektur an für die Veränderungen des Winkels zwischen der senkrechten Richtung und der Sitzrückenlehne, welcher für diese Wagenart einen beträchtlichen Wert

annehmen kann. Dieser Korrekturfaktor wurde aus Durchschnittswerten der mit 25 Wagenführern durchgeführten Messungen erhalten, wobei ein Sitz mit einem veränderlichen Rückenlehnewinkel verwendet wurde. Diese Charakteristik der Augenlage ist sehr einfach und wurde angenommen, um die Puppenverwendung zu vermeiden und weil sie für die nötigen Vergleiche als ausreichend angesehen wurde. In der Praxis gab sie manchmals irreführende Ergebnisse, z.B. im Falle einer grossen Variabilität der Sitzepolsterweichheit.

Man hat Personen- und kommerzielle Wagen verschiedener Typen untersucht, und es wird ein typisches Untersuchungsergebnis aufgeführt. Die Hauptvergleichspunkte der Wagen sind die folgenden : das Mass der durch die Windschutzscheibensäulen und die Motorhaube verursachten Verdeckung in der Richtung nach vorne, sowie der senkrechte und wagerechte Winkel des rückwärtigen Gesichtsfeldes. Diese Faktoren hängen von der Ausführungsweise der Wagen ab. Insbesondere wenn die Dachlinien niedrig verlaufen, befindet sich das Auge im Wagen gewöhnlich auf dem Niveau, wo die Säule in der Dachnähe eine Verstärkung erfährt, was zu beträchtlichen Verdeckungen führt. Das hohe Augenniveau begrenzt ebenfalls die Wahl der Lage der inneren Spiegel : es ist nämlich schwer, eine gute Rückwärtssichtbarkeit zu erzielen, ohne eine unerwünschte Verdeckung in der Richtung nach vorne zu verursachen.

AN EXPERIMENTAL STUDY OF CONTROL CONSOLE DESIGN

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This study was concerned with a systematic evaluation, through a series of experimental trials, of the angular orientation of the side panels of an operator's console. Since both a single operator and paired operators had to be accommodated, the trials embraced both of these conditions. Seven different measures were used. The single operator data showed a consistent pattern pointing to the choice of the greatest angle (closest to the operator) tried. The paired operator data gave inconsistent indications. A balanced resolution of all the data indicated a choice of 50° or 55° as the best angle taking all the conditions of use into consideration.

§ 1. Introduction

Morant (1954), in discussing how body measurements may be used in dealing with a workspace problem, points out that they give no idea of tolerable ranges of movement. He says, " But the complicated ways in which the body adapts itself in different attitudes and tolerances in movement are the essence of the problem of determining the best dimensions of a workspace which is to be used by a number of people. Also, the data for body measurements by themselves fail to take into account other conditions which are always encountered in dealing with a particular problem, such as ease in operation, comfort, visual requirements and safety clearances."

He describes both a drawing board method of fixing spatial requirements and a method utilizing the spatial envelopes established by general investigations. Nomographic renditions of such data are presented, for example, by Ely *et al.* (1956). But Morant suggests a third method which " can best be used in practice ". This is the " Method of Experimental Trials " requiring a mock-up of the workspace, a selection of subjects to perform suitable tasks, observations of their performance, a decision based on the observations and interpretations in engineering terms.

In the study here reported, a console consisting of a centre panel and two side panels had been decided upon but the question relating to the angle to be given the side panels relative to the centre panel remained open. Since the console was to be designed so that it would be suitable either for a single operator or for a pair of operators, an optimal resolution of the conflicting requirements of these two operating situations had to be found.

The example under consideration was the control console for the computer subsystem of a missile system. It was of the low ' wrap-around ' type in which the operator is confronted by a three-sided, low control and display array, but is able to maintain visual surveillance beyond the console by having unrestricted vision over the top. The design called for a centre panel approximately 48 in. long and 17 in. high, and two side panels, each approximately 36 in. long and 17 in. high. All the panels were sloped back from the vertical. Desk table surfaces (17 in. wide) were provided in front of each.

The problem was to find the best angle between the front panel and the two side panels, taking into account that two operators might often be required at the console although there would usually be only one.

It would be generally agreed that a well-designed console should place all displays and controls within easy reach of the operator without requiring large movements of chair or body. Therefore, the aim of the design should be to minimize body, arm and chair movements required to actuate controls. Similarly, all visual displays should be within the range of unrestricted vision with minimal head motion.

§ 2. Method

2.1. *Mock-up*

A wood and masonite full-scale mock-up of the console was built. Incorporated in the design were provisions to vary the angle of the side panels relative to the centre panel from a minimum of 30° removed from the in-line arrangement to about 70°. Thus, the larger the angle, the closer the side panels would be to the operator. A sample of the controls and indicator lights was mounted on the console panels. The controls included toggle switches, rotary switches and push buttons and represented all types and locations. Each was labelled in sequence from left to right. A desk-type upholstered swivel chair with arms and with the seat set at 18 in. above the floor was employed. Two of these chairs were used with the paired operators.

2.2. *Operating Programmes*

Three operating programmes were constructed and revised after trial to provide three levels of performance difficulty. Each step consisted of an instruction such as: Shift C8; Press R6; Rotate L1; etc. Programme I, of ten steps, was confined to operation of controls on the centre panel, and thus offered a series of relative ' easy ' manipulations. Programme II also included ten steps but, in this case, the first five steps required control manipulations on the left panel and the second five required control manipulations on the right. This programme was, in consequence, somewhat more difficult. Programme III, of ten steps, required two manipulations in each step, one on either of the side panels and the other on the opposite side panel or centre panel: it thus, called for a double quantity of manipulations and was of significantly greater inherent difficulty.

2.3. *Test Series*

Two series of tests were conducted: the first for single operators; the second with paired operators. A test series for any one operator or pair of operators consisted of twelve programmes: three for each of four side panel angles; 35°, 45°, 55° and 65°. Programmes and angular positions were randomly varied for different subjects.

Instructions to the subjects were that they perform whatever motions appeared ' natural ' to complete the steps of the programmes. Chair motion, body movement and arm movement were not restricted. Either arm was to be used as desired.

2.4. *Subjects*

For the single operator tests, eleven subject-operators were used. According to anthropometric data on heights of enlisted airmen (O.N.R. 1952), the average height is approximately 5 ft 9 in. and the range from 5 ft 6 in. to 6 ft. 0 in. would include over 73 per cent of all enlisted men. Subjects were selected from within this range in such a way that seven of the eleven subjects used in the present work were of ' average ' height, two subjects were ' moderately short ' and two subjects were ' moderately tall '. Six pairs of subjects were used in the paired operator trials with representation of all three height classes, combined and positioned (right-left) randomly.

§ 3. Results

3.1. *Measures of Performance by Single Operators*

The mean numbers of seat movements are shown in Table 1 and the mean seat displacements in Table 2. Both show, on average, substantial reductions as the side panel angle is increased especially in the most difficult Programme III.

Table 1. Mean Number of Seat Movements for Single Operators

Side panel angle	Programme I	Programme II	Programme III
35°	0·8	3·5	9·4
45°	1·4	3·9	9·1
55°	0·8	3·5	8·3
65°	0·8	2·7	6·2

Table 2. Mean Seat Displacement (in inches) for Single Operators

Side panel angle	Programme I	Programme II	Programme III
35°	14·1	170·5	111·0
45°	15·3	147·0	105·5
55°	10·7	112·2	95·9
65°	10·8	71·0	40·1

The figures are the means per subject of the sum of the displacements from centre position at each step, whether or not seat *movement* occurred. Displacement was measured by means of a spring-loaded tape-measure.

Numbers and extents of body movements are shown in Table 3. Each subject's normal sitting position was noted and any deviation from this position was noted for each step. ' O ' was recorded for no appreciable deviation; ' + ' for a definite but limited deviation; and ' + + ' for extended body movement. Data for arm extensions are given in Table 4. For each step a distinction was made between ' partial ' and ' full ' arm extension. In the latter case, the elbow was practically straight and the fingers and hand were maximally extended. It appears that neither type of movement was much affected by the side panel angle. It therefore seems that the effects of side panel angle were shown more in changes of the operator's position than in the extent to which he reached from a given position.

The data were further broken down according to the heights of the subjects and it was found that, for obvious reasons, the shorter subjects made more and greater seat movements and somewhat more large body and arm movements than the taller. The relationships between the different measurements and side panel angles seemed, however, not to have been affected by the height of the subjects.

Table 3. Mean Number of Body Movements for Single Operators

Side panel angle	Degree of movement	Programme I	Programme II	Programme III
35°	0	5·1	4·5	4·7
	+	4·0	4·4	4·2
	++	0·9	1·2	1·1
45°	0	5·7	4·5	4·8
	+	3·5	4·5	4·5
	++	0·8	0·9	0·7
55°	0	5·3	3·9	4·7
	+	4·1	5·1	4·4
	++	0·6	1·0	0·9
65°	0	5·4	4·9	4·7
	+	3·8	4·5	4·3
	++	0·8	0·5	1·0

Table 4. Mean Numbers of Arm Extensions for Single Operators

Side panel angle	Degree of arm extension	Programme I	Programme II	Programme III
35°	Part	4·5	5·1	4·2
	Full	5·5	4·9	5·8
5°	Part	5·3	4·5	4·4
	Full	4·7	5·5	5·6
55°	Part	5·3	4·5	3·9
	Full	4·7	5·5	6·1
65°	Part	5·3	4·9	3·1
	Full	4·7	5·1	7·0

3.2. *Scores for Paired Operators*

Since with the paired operators seat movements rarely occurred (four movements of small displacement throughout), no tables of these data are presented. Data for body movements are presented in Table 5 and for arm extensions in Table 6. Both show a tendency to increase with side panel angle in Programme I and to decrease with angle in Programmes II and III. This is perhaps understandable in that the close grouping of the controls in Programme I would make the operators tend to get in each other's way, whereas they could divide the task between them more easily in Programmes II and III.

Table 5. Mean Number of Body Movements per Pair of Operators

Side panel angle	Degree of movement	Programme I	Programme II	Programme III
35°	O	7·2	5·0	7·1
	+	2·0	3·5	2·1
	++	0·8	1·5	0·8
45°	O	6·0	5·8	6·8
	+	3·5	2·2	1·9
	++	0·5	2·0	1·3
55°	O	5·7	6·3	7·2
	+	3·5	2·2	2·6
	++	0·8	1·5	0·2
65°	O	5·0	9·2	9·7
	+	4·3	0·8	0·3
	++	0·7	0·0	0·0

Each of the two operators sometimes blocked the other's view of the control being manipulated. As an indication of this, the operator who was not manipulating a control said 'check' or 'no check' at each step, depending on whether or not he could see the other operator's action. The frequencies of such visual blocks are given in Table 7, and they are there shown to increase markedly with side panel angle in Programmes II and III.

Table 6. Mean Number of Arm Extensions per Pair of Operators

Side panel angle	Degree of arm extension	Programme I	Programme II	Programme III
35°	Part	7·0	4·0	5·3
	Full	3·0	6·0	4·7
45°	Part	5·7	4·3	6·1
	Full	4·3	5·7	3·9
55°	Part	4·7	5·3	6·2
	Full	5·3	4·7	3·8
65°	Part	4·5	7·5	8·2
	Full	5·5	2·5	1·8

Table 7. Frequency of Visual Block with Paired Operators

Side panel angle	Total	Programme I	Programme II	Programme III
35°	4	—	3	1
45°	12	—	9	3
55°	16	—	7	9
65°	40	—	19	21

The indications for large side panel angles with paired operators were much less clear than they were with single ones. When the angle is large the paired operators tend to reach more in certain circumstances and also to block each other's view of the panels.

3.3. *Subjective Assessments by the Subjects*

Difficult–easy evaluations. At the conclusion of each programme the subject was interviewed in order to gain further insight into any difficulties he may have encountered in the manipulations required. A five point scale was used: (1) all difficult; (2) most were difficult; (3) some difficult, some easy; (4) most were easy; (5) all easy. 'Difficult' was generally defined as implying "greater effort than a well-designed console should be expected to demand". For the paired operators separate evaluations of visual and manipulative difficulties were obtained.

Wider–closer evaluations. Upon completion of all three programmes with one of the side panel angles, the subject was asked to state his general evaluation of the 'workability' of that side panel angle. If the angle was considered workable, a statement was made as to the desire for a wider or closer angle. If not workable, a statement of reasons was solicited. The wider–closer evaluations were scored using the following scale:

+5·00 = workable, a closer angle is definitely required;
+3·00 = workable, but a closer angle would be much better;
+1·00 = workable, but a closer angle would be somewhat better;
0·00 = workable, excellent, cannot be improved;
−1·00 = workable, but a wider angle would be somewhat better;
−3·00 = workable, but a wider angle would be much better;
−5·00 = workable, a wider angle is definitely required.

3.4. *Preference Ratings*

Upon completion of all programmes with all wing angles, the subject assigned a preference ranking (1 to 4) to each of the wing angles. ' First ' was scored as ' 1 ', while ' fourth ' was scored as ' 4 ', with the intermediate ranks given the intermediate scores. Thus, low scores indicate high preference and high scores indicate low preference.

Table 8 presents a summary of the data for the difficult–easy, wider–closer and preference evaluations for the *single* operators. The difficult–easy consensus was at a point somewhat greater than ' most were easy ' (4·15) for the 65° wing angle. Evaluations of the other side panel angles showed distinctly lower scores. The wider–closer evaluation scores indicate a steady desire for closer angles, even with the closest used in these tests, i.e. 65°. The Preference Rankings were unanimous. The four side panel angles were rated from first to fourth in this order: 65°, 55°, 45° and 35°. The subjective data are thus consistent with the performance measures.

Table 8. Difficult–Easy, Wider–Closer, and Preference Evaluations of Single Operators

Side panel angle	Difficult–Easy	Wider–Closer	Preference
35°	3·64	+3·00	44
45°	3·58	+2·82	33
55°	3·94	+1·45	22
65°	4·15	+0·64	11

A summary of the data from the difficult–easy, wider–closer and preference evaluations of *paired* operators is presented in Table 9. The most revealing point of the difficult–easy data is that the 35°, 45° and 55° angles were given nearly equal evaluations as regards vision, but the 65° wing angle was rated as more difficult. For manipulation, the difficult–easy evaluations reveal slightly greater ease as the angles are increased. The wider–closer data indicate a shift from positive to negative scores with the zero axis (excellent) crossed at about 50°. The preference data for paired operators support an angle of 55° or a little less.

Table 9. Difficult–Easy, Wider–Closer, and Preference Evaluations of Paired Operators

Side panel angle	Difficult–Easy		Wider–Closer	Preference
	Vision	Manipulation		
35°	4·83	4·56	+1·42	37
45°	4·64	4·64	+0·92	21
55°	4·61	4·92	−1·00	16
65°	4·08	5·00	−2·67	36

§ 4. Discussion

In general, the single operator data point to a choice of as great an angle, at least up to 65°, as would be compatible with other requirements. Therefore, the selection of an angle which is less than 65° would depend upon the implications of the paired operator data.

From the paired operator visual block data, it appears that difficulties arise with angles greater than 55°. These are especially serious if paired operators must see all control manipulations and displays on all parts of the console. Both the wider–closer data and the preference ranking data indicate an optimum angle at about 45°–55°.

On the assumption that the paired operator and single operator situations be assigned equal importance, the selection of an angle of 50°–55° appears to be the best resolution of the conflicting effects of side panel angle.

L'objet de cette étude était la détermination systématique (au moyen d'une série d'essais expérimentaux) de l'orientation angulaire des deploiements de côté de ' Control Console '. Comme il est nécessaire d'envisager un seul opérateur ainsi qu'une paire d'opérateurs, toutes les deux conditions étaient prises en considération dans les essais. On a employé sept mesures différentes. Les valeurs obtenues avec un seul opérateur montraient toujours un groupement indiquant le choix de l'angle le plus grand de tous les angles essayés (le plus proche de l'opérateur). Les valeurs obtenues avec les opérateurs pairés indiquaient le choix de 50–55° comme le meilleur angle, toutes les conditions d'emploi étant prises en considération.

Der Gegenstand dieser Untersuchung war die systematische, in einer experimentellen Versuchsreihe durchgeführte Bestimmung der Winkelorientation der Seitentafeln einer bedienten Konsole. Da die Bedienung nicht nur aus einem Individuum, sondern auch aus einem Paar von Menschen bestehen kann, bezogen sich die Versuche auf diese beiden Bedingungen. Man hat sieben verschiedene Mensuren angewandt. Die mit Einzelbedienung erhaltenen Werte ergaben immer ein Bild, welches darauf hinweist, dass der grösste der versuchten Winkel (am nächsten zum Bedienungsmann) gewählt wird. Die mit einem Bedienungspaar erhaltenen Werte zeigten, dass 50 oder 55° als bester Winkelwert gewählt wurde, wobei sämtliche Verwendungsbedingungen berücksichtigt wurden.

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ON THE ACCURACY OF INSPECTORS

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Reasons for inspector inaccuracy have been examined in three main groups: reasons of basic individual abilities; of formal organization (training, instructions, physical conditions, the lay-out of the job); and of interpersonal relations and social relations. Without denying the importance of the basic individual abilities of inspectors, which must set the ultimate limits of accuracy, it seems that the actual limits in a working situation are set by the other two groups of reasons. These practical limits may be well inside the limits set by basic psychological and physiological functions. For example, given an inspector who is well equipped with the basic abilities and aptitudes for the actual inspection task itself, he cannot operate more accurately than his instructions, for instance, allow him to. Moreover, even if well selected, well trained and well briefed, he still can be no more accurate than the pressures of interpersonal and other social relations permit. These interpersonal relations do not necessarily make him pass work that should be failed; they may also make him fail work that should be passed. Conversely, the production man will be more eager to 'get products past', to trick the inspector, when he does not 'sanction' the inspector. This may in turn make the inspector reject more of the work of the man who tries to trick him than is actually bad. These interpersonal and social relations become all the more important when the inspection task is the more 'socio-technical'—involving direct interaction with production.

It seems that when relations between production and inspection are poor, when production feel they cannot sanction the inspectors and/or their standards, and when inspection chooses to play its role in a dominant, authoritative, and essentially invidious way, rather than as finding neutral facts, then not only will inspector accuracy be adversely affected, but there will also be strong pressures against inspection supervisors testing their inspector's accuracy.

Although the obvious man to check inspector accuracy is the inspector's own supervisor, there are powerful pressures against his doing this. Not only are there practical difficulties, but also there is the fact that inspection supervisors, and others, tend to become 'product-bound', even to the neglect of their true supervisory duties. Moreover, the pressures of interdepartmental relations encourage inspection supervisors to see themselves first as inspectors, and only secondarily as supervisors.

The general conclusion is that inspector accuracy, in a working situation, is determined by a wide range of factors. Problems of inaccuracy must then be studied in a wider context than is given by any single approach.

§ 1. Introduction

One of the aims of Ergonomics is to bring to a focus on problems of work behaviour not just one but a number of different approaches. The purpose of this paper is to suggest that problems of inspector accuracy are among those that are unlikely to yield to any single approach. Laboratory experiments on individual efficiency, the approach by way of psychological abilities and aptitudes, the study of environmental factors, the study of 'situational' and social factors and of the personal relationships involved, and the study of 'organizational' factors, all of these seem to have their contribution. Any one of them, by itself, could deal with perhaps only a small part of the problem.

§ 2. Background

In a study* of human relations between inspection and production departments in factories where inspection is separated off as a specialist function it was found that the consistency of the same inspector examining the same products on different occasions, and the consistency of different inspectors with one another, was often much lower than was assumed in the factory. Results of experiments in that study (McKenzie and Pugh 1957) seem very much in line with other observations. It appears that, when clear-cut tests are made, much greater inconsistency is found than was expected in tasks ranging from the objective type—'go–not go' gauging, micrometer measuring (e.g. Lawshe and Tiffin 1945)—through more subjective ones such as inspection of soldered connections, of knitting, and of the gumming of paper, to the highly subjective judgements such as inspecting surface finish of metal parts, and judging the noisiness of mechanisms in operation. Similar inconsistency is found at various 'skill levels'. The correlation between the marks given to examination answers by university lecturers—colleagues of long standing—may be as low as $+0{\cdot}53$. Doctors differ considerably in their diagnosis of tuberculosis based on x-ray films (e.g. Clayson *et al.* 1955). Skilled adjusters of telephone selector mechanism will always find something to adjust, even though the mechanism is fresh from overhaul by a colleague (Preist 1954); on one item of a maintenance schedule, ten skilled men, each in turn overhauling the identical mechanism but not being aware that it was the same one, each faulted the adjustment made by the previous man, and readjusted it, only to have the 'readjustment' faulted by the next man and readjusted yet again.

§ 3. The Effect of Individual Basic Abilities

On closer examination reasons for inspector inaccuracy seem to fall into three main groups: reasons of basic individual abilities, reasons of environment and of formal organization, and reasons of interpersonal and of social relations.

The ultimate limits of accuracy must presumably be physiological and psychological. Thus accuracy in reading a measuring instrument must be limited by the resolving power of the eye in distinguishing, for instance, minimal misalignments of two lines. Micrometer accuracy is eventually a function of the user's tactual and visual acuity. Checking articles for colour match requires good colour discrimination. Checking noise level may be limited by the tester's discrimination of pitch.

Again, limits may be set by the degree to which the state of attention can be controlled. Mackworth (1956) has shown how rapidly vigilance deteriorates after even the first half hour of a task requiring intense attention. In visual watching, 16 per cent of signals were missed in the first half hour, but 26 per cent in the second. This sort of task is obviously analogous to many inspection tasks. Similarly Saldanha (1955) trained men to set, to one-thousandth of an inch, a series of readings on a Vernier caliper gauge, by turning a small hand-wheel. During the eighth quarter-hour period of the two-hour spell of work,

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the average amount of error was 64 per cent greater than in the first quarter-hour period.

Mitchell (1935 b) suggested that it was important for inspectors to be 'alternators' rather than 'perseverators', so that they could easily switch their concentrated attention from one type of fault to another, or indeed from one inspection task to another. Wyatt and Langdon (1932) suggested that since many inspection tasks make such demands on attention and yet are essentially simple and repetitive—the optimal conditions for boredom occurring—inspectors should rotate tasks, working for, say, an hour on one job, and then changing for the next hour to as different a task as possible. They found that such a change increased output and, in particular, improved accuracy.

Raphael (1942) on the same point, found it important that inspectors should have a break in their work, even by arranging that they could at choice either sit or stand at their work, or that they themselves collect the work they have to inspect. Similarly, she suggested that attention should be given to the size of the batch the viewer works on, suggesting that it be such as could be completed in less than two hours.

All these points apply particularly to tasks involving long spells of viewing. But it often turns out that spells of 100 per cent viewing are in fact broken up. Also, it is common for inspectors to do several quite different tasks in the day, and yet still to be inconsistent.

In these psychological and physiological abilities there may be a wide range of individual differences; this is the *rationale* for the selection approach. But to discover just what abilities are relevant is not easy. Wyatt and Langdon (1932) summed up their work on selection by suggesting that the best viewers tended to excel in visual observation and discrimination, and also appeared to be above average in intelligence. But they did not find any marked common factor between tasks; they concluded that a 'work-sample'—a standardized form of the specific inspection task—might give better results than tests based on analysis of the psychological functions involved.

However, some useful research has been done on selecting inspectors. Simple visual acuity is sometimes important. Thus in inspecting soldered connections, when 20 deliberate errors were set up in a batch of 1000 connections the average 'catch' by 39 experienced inspectors was only 83 per cent of the errors. At the lower end, four inspectors round 14 out of 20 faults, four found 13, and one found only 9. When the men's vision was tested, twelve of the eighteen who scored 90 per cent or more were found to have 'exceptional' vision, and three more had vision rating 'acceptable'. But of the twenty-one who scored lower, only six had vision as good as 'acceptable' (Jacobson 1953).

Thus in this case vision is important, but not the only factor. Similarly, the study of general intelligence, of perceptual discrimination, and so on, takes us, in some tasks, further along the road but by no means all the way. One difficulty is that accuracy for one defect may require different abilities than does accuracy for another defect. Thus in inspection of metal sheets for different appearance defects, Tiffin (1943) found that the highest inter-correlation of accuracy for any two types of defect was only $+0{\cdot}35$. But many inspection tasks do involve looking for several different defects. Moreover, an inspector often does several quite different tasks in his daily round, especially when inspection

is of the patrol type, rather than 100 per cent viewing. This makes selection based on abilities related to accuracy very difficult.

Moreover, much may be done to improve accuracy without ever involving these basic abilities. Evans (1951) for example, found that a seven-hour programme of training in the use of the micrometer considerably improved accuracy. But training of this duration could hardly have made much change in the subjects' basic levels of tactual and visual ability.

§ 4. Reasons of Environment and of Formal Organization

Under this next, rather vague, heading of reasons for inaccuracy are grouped such factors as the definition and transmission of standards, the instructions and training given to inspectors, and the physical structure and environment of the inspection task itself.

It is often found, once a strict test of accuracy raises the question, that the inspectors concerned have had only the scantiest instructions. Raphael (1942) described how some of the viewers inspecting a fabric product were rejecting 53 per cent of the product, while others in the same group were rejecting only 13 per cent. The reason turned out to be, not differences in perceptual ability, but the simple fact that, while the specification allowed a tolerance of 3 millimetres, " some of the viewers did not realize this."

In one of our experiments considerable inconsistency was found in ' go–not go ' gauging of a small internal bore. Examination showed that the viewers had different notions about whether it was permissible for the tip of the ' not–go ' gauge to enter the bore or not, and, if so, how far. Of course, this did not account for all the inaccuracy; individual viewers were themselves inconsistent from one trial to another. But the point is that even ' go–not go ' gauging—an apparently fool-proof process—requires clear instructions. Similarly, rejections for surface finish out of a batch of 50 parts ranged from 20 per cent by one viewer to 56 per cent by a colleague. The chief inspector rejected only one part—one of the 4 not until now rejected by anyone in any trial. It turned out that viewers were never given actual samples of acceptable and unacceptable finish. It was argued that such samples would themselves change in appearance through time. An answer would be that for each type of product the inspection supervisor should pick out a few acceptable and unacceptable articles at the beginning of each week, or even each day, as a guide to his inspectors. To prevent the standard depending on one man, this ' calibration ' might be done by a weekly half-hour panel of all inspection supervisors. Indeed, production supervisors, too, might well attend.

Again, in an experiment on noise-testing, by the time three testers had each made two judgements of a batch of 8 products, every product had at some time been passed, and every one had also at some time been rejected. While there were instructions somewhere about the procedure, observation showed considerable differences in practice; for instance, one man would keep the product at arm's length on the bench; another would bring his ear right down onto the product. Moreover, although gauges in that factory were regularly calibrated against master gauges, inspectors were never calibrated, for instance, by having these noise testers together listen to a series of products in order to achieve common standards. The result was that some testers considered a particular noise symptom must always lead to rejection, whereas to others the same

symptom was an unimportant ‘ bedding-in ’ noise. A standard was indeed provided, in the form of a ‘good’ product. But it weighed a good many pounds, and was stored on the floor. To refer to it involved disconnecting the power from the product under test, lifting up the standard from the floor, connecting it up, listening to it, disconnecting it, re-connecting the doubtful one and listening to it again. Obviously, the stituational scales were heavily set against the standard being often referred to.

Sometimes the reason why ill-defined standards, or subjective judgements, cause trouble is not simply that the inspector judges inconsistently, but that, whatever his judgements—and they might actually be accurate and consistent—he cannot get them accepted by production people unless they are supported by clear evidence. There is a distinction between ‘perceptual’ and ‘behavioural’ inaccuracy. Thus Belbin (1957) describes how, in a knit-wear factory, inspectors reported very few ‘ seconds ’; instead they classified nearly all defective work as ‘ mendable ’. The point was that while the knitters lost pay for defective work, they lost more for ‘ seconds ’ than for ‘ menders ’. Lacking clear standards the inspectors could not resist the pressure from the knitters to class most defects as menders. Thus, clear standards are important not just for individual efficiency, but also to give the inspector support in the interpersonal relations of inspection.

Similarly, there is the problem of the inspection supervisor’s desire to keep on good terms with his own inspectors. In another experiment on surface finish, two viewers both rejected the same parts, giving 100 per cent consistency. But one viewer, in addition to rejecting these parts, apparently considered 20 more parts to be borderline, and spent some time rubbing them down with emery cloth. The foreman considered the first girl’s standard was correct. He said he knew the second viewer was fussy, but that he had not realized she was so fussy as this. Nonetheless, he did not intend to tell this girl her standard was too high, for fear this might upset and discourage her.

A point that reduces the chance of inspectors being trained or calibrated seems to be the feeling that the ‘ experienced ’ and ‘ responsible ’ man needs no instructions, even for a job that is new to him. Without decrying the value of experience, it is fair to point out that Evans’ journey-men toolmakers—experienced in using micrometers—were no more accurate than apprentices. All the doctors in the experiment on reading x-ray films were highly experienced, yet they were themselves astonished at their inconsistency. In the noise-testing experiment described above, the tester who, in his second trial, reversed more of his original judgements than anyone else (four out of eight), was the most experienced. In an examination marking experiment the lecturer whose self-consistency was lowest was far and away the most experienced of the markers.

Thus, inspector consistency is affected by poor definition of standards, by lack of instructions, and by lack of calibration of inspectors with one another. Even more important than ‘ original ’ training is ‘ continued ’ training; Evans showed that improvement in micrometer accuracy had to be maintained by periodical doses of supervised practice, each measurement being immediately checked.

Under this heading also come environmental factors such as lighting. Wyatt and Langdon found that the output of viewers dropped by 5 or 6 per cent on the change to artificial lighting. Raphael stressed the importance of the background

against which parts are inspected; this should be such that the parts stand out in contrast against it. Glare may be important. In a set-up for detecting cracks in shiny metal rods we found that the light source—though bright—was at such an angle that its light struck the work at an angle and reflected a high light into the inspector's eyes. This dazzle meant that cracks, even when full of crack-detecting fluid, could easily be missed.

Thus sheer intensity of light is not necessarily the answer. Similarly, control of glare is not necessarily a matter of completely eliminating it. Some inspection tasks, for instance of gloss finish, can only be done under light from the front, reflecting off the surface of the product and into the inspector's eyes, and thus showing up any matt patches. The important point here is that when the artificial light is switched on, the light may come to the work from a different angle than does daylight. Mitchell (1935) described the inspection of gumming of paper. Under artificial light, mis-sorts ran at from 10–13 per 1000 sheets, but only at 3 per 1000 in daylight. It was found that the artificial light reflected two points of high-light onto each sheet; only at these points could the gloss of the gum be accurately checked. The answer was a tubular light low over the far end of each viewing table. In effect, this gave a low intensity glare, evenly distributed over the whole sheet of paper.

Then there are the apparently simple matters of how the gauges or scales are marked. Juran (1951) points out that if a meter is marked not in single units but at every second unit, then the distribution of readings made shows alternate peaks, at the marked units, and valleys, at the unmarked ones. A measurement that falls between markings tends to be ' rounded off ' towards the nearest actual marking, rather than towards the middle—unmarked—unit. Even where every unit is marked, there is a tendency to ' round off ' readings to the nearest marking. Similarly, Juran shows that at the maximum permitted limit—of, say, 30 units on the scale—there may be a sudden pile-up of readings, and then perhaps none at all at 31, 32, or 33 units. Here the inspector is doing what production often say he should do—trying to pass products rather than to fail them. Again, study of a task from this ' situational ' point of view may show that to reject a batch involves the inspector in some paper work, interrupting his flow of activity. Thus the set-up is inherently biassed towards his passing the work rather than rejecting it.

4.1. *' Sets' and Social Norms among Inspectors*

Production people sometimes complain that inspectors tend to ' get a complex '—as it was put to us—about a particular fault. " Causes of rejection " said a production manager " seem to me to run suspiciously in cycles." Another aspect of this is that the inspector is often ' set', as it were, to see work as bad rather than good. He is, after all, looking for faults, and indeed has a vested interest in them. This ' set ' may be his general attitude, or, as we shall see, it may be limited to a particular operator. Moreover, if one inspector has a basic preparedness to respond to borderline products by rejecting them, whereas another has a similar ' set ' to respond by accepting them, this could account for much inconsistency.

It sometimes happens that ' social norms ' of rejection develop (presumably originally based on experience), so that by and large the same number of products is always rejected. When the inspection task is highly ' relational '—when the

inspector knows whose work he is examining and has to face the operator directly —to reject always the same proportion reduces the chance of argument, and also defends the operator against a superior investigating why the proportion has changed.

But, norms of rejection occur in non-relational tasks, too. Mitchell (1935 b) describes how, in one department, improvement in method had doubled production. The quality of the work should not have changed, yet the percentage of rejects was only half what it had been before. It turned out that the inspectors were still rejecting the same total number of pieces in a day as they had always done, although twice as much work was now being produced. "The inspectors had a fixed idea of the number of pieces to be thrown out, which remained unaffected by the additional number handled."

In one noise-testing experiment we saw a clash between a ' norm of expected rejections ', a ' set to pass ', and actual judgement. In that experiment, 25 products were tested by three testers in turn. Tester A rejected 11 of the 25, B rejected 3, and C rejected 5. The charge-hand inspector contended that A was putting his standard higher than usual just because he was being observed. So the charge-hand had some sort of norm in mind, and one lower than 44 per cent. The charge-hand was incensed by A's stupidity, and stormed off to show how the testing should be done. He was thus ' set ' if not to pass products willy-nilly at least to pass more than A had done. In the event he rejected only 5 products where A on two trials had rejected 11 and 10. However, he rated 3 more as ' borderline ', remarking each time " A good one . . . But mind I could understand anyone rejecting it ". Each of these 3 had been rejected by A on both trials, and in fact two of them had been rejected by everyone but the charge-hand himself. We must suspect that, had he not been trying to prove A over-zealous, the charge-hand would have rejected at least 8 of that batch—3 less than A, but just twice as many as the average of the other two testers. The other two testers were apparently rejecting at a rate within the charge-hand's norm, as evidenced by the little interest he showed in their rates. Yet tester C rejected almost twice as many products as B. Moreover, of the 3 products rejected by B, the charge-hand in fact rated one as good, and the other two as good but border-line. Thus, it seems that so long as an inspector's total rates of rejection stay within the accepted norm, then his actual accuracy is unlikely to be examined.

§ 5. Reasons of Social Relations and of Interpersonal Relations

In the factory, inspection is always, if implicitly, of people; inspection decisions about a man's work directly reflect on him. Moreover, many inspection tasks are subjective ; thus the personal relationship between inspector and operator may influence the inspector's judgement without his being aware of it ; sometimes, of course, the effect is entirely conscious. Thus an inspection task done in a factory is very different from the same task done in a laboratory. In the factory it is done in a cogent social context, and through some sort of personal relationship.

Various factors may be involved. Thus sheer physical location may be important. In one factory two operators and one inspector worked together all day long at one end of a high, gloomy, and echoing building, with nobody else present except on the occasional visits of supervisors. Obviously, there was a strong tendency for the three to identify themselves as a group, and therefore

for the inspector not to make many decisions that might disrupt the group, even though, formally, he belonged to a different department. Here again the accept-reject standards would have to be very clear and objective before the inspector could feel ' justified ' in making adverse decisions.

This is not to say that operators in such circumstances suborn the inspector, or ' send him to Coventry ', although to suggest that they do is a common over-simplification of the effect of ' informal ' social pressures. For similarly we find production supervisors themselves opting out of their quality responsibility —" it's up to you inspectors to look after quality "—for fear that ' niggling ', or imposing standards that neither they nor their operators fully sanction, will upset relations with the operators. Similarly, the very inspection supervisor may fail to correct his inspector's standards for fear of upsetting her.

Again, in a situation where girls inspect the work of men, in direct interaction with them, there is a fair chance that the men will resent the girls being functionally superordinate. To maintain ' good working relations ', the girls are likely to discover that they have to ' under-act ' their inspection role, for example, by reporting only a token total of rejects, or rejecting only defects so obvious that the men can accept their decisions without feeling they lose face. Similarly, we have Belbin's example where the inspectors could not resist the pressure of the knitters to grade rejects as high as possible, because they lacked the support of clear definitions.

On a more intimate plane, Mitchell (1935 b) recounts how a lad complained that the inspector was rejecting work done by him which would have been passed had it been done by anyone else. A test was made, unknown to the inspector or to the lad, and it was found that the latter's allegations were true. The investigator in conversation led the inspector to comment on this worker, and found that he genuinely believed the lad produced more poor work than anyone else. " Besides," he added " he's an impudent young rascal, and a thorough nuisance all round."

The investigator suggested to the boy that he should try the effect of showing a little more deference to the old fellow on the inspection bench. Some time later the question was raised again with the inspector; now he said that the lad " had improved very much, and looked like becoming one of the best workers in the shop."

In passing, it will be seen that here the inspector was much older, had more experience, and more service, than the production lad. The inspector expected the deference ordinarily felt in our society as due to these attributes, as well as acceptance of his formal superordination as an inspector. When he did not get it, his attitudes to his junior's work became unfavourably coloured, as do the attitudes of most of us towards the work of people whom we regard as juniors but who do not behave in the way we think our juniors ought. But because this inspector's superordinate formal status was in fact also supported by his seniority and greater experience, it was possible for the boy to behave with suitable deference when this was suggested. Had it been the operator who was the old man, and the inspector the young one, the investigator would have had to do a deal of persuading to get the operator to act with more deference.

Another example of the effect on inspection judgements of the inspector–operator relationships comes from the Hawthorne investigations (Roethlisberger and Dickson 1950). In the Bank Wiring Observation Room a group of 14 men

were observed daily for several months. In the group were 9 wiremen, who wired banks of connections on telephone exchange equipment, 3 solder-men, who soldered these connections, and 2 inspectors who examined wiring and soldering 100 per cent. Later, one inspector was replaced by another so that 3 different inspectors were involved altogether.

It was decided to see whether relations between the men affected the judgements of the inspectors. The investigators excluded figures of objective defects, such as 'no solder' or 'cross solder'. Moreover, only defects for which the soldermen alone could be responsible were included. Figures were available from all three inspectors of their judgements of the work of Solderman 2, when he was soldering connections wired by Wireman 5. Inspector 1, examining Solderman 2's work on Wireman 5's wiring, found an average of 444 such defects per 100 000 terminals soldered. Inspector 2, however, examining Solderman 2's work on Wireman 5's wiring, found far fewer, namely 363, while Inspector 3 found rather more, namely 474. Similarly, when the same solderman was soldering connections made by Wireman 6, he was charged with almost twice as many defects by Inspector 3 as by Inspector 2, 537 against 297.

But apart from the different levels of rejection by different inspectors of the same solderman's work, it seems that the wireman is somehow involved, too. For Inspector 2, examining Solderman 2's work, found fewer soldering defects when the wiring had been done by Wireman 6 than when it had been done by Wireman 5, namely 297 against 363 per 100 000. Perhaps this might be because Wireman 6 wired tidier connections which were easier to solder neatly. Yet Inspector 3, on the other hand, still examining Solderman 2's work, found *more* defects when the wiring had been done by Wireman 6 than when done by Wireman 5—537 against 474. Similarly, Inspector 1, checking the work of Solderman 1, found different proportions of solderman defects according to who had done the wiring. This inspector found 414 faults per 100 000 in Solderman 1's work when wired by Wireman 1, 440 when wired by Wireman 2, and only 235 when wired by Wireman 3—a range of difference of more than 200 defects per 100 000 terminals.

Considering that the only defects included were ' excess solder ', ' poor solder ' and ' splash solder ', all the responsibility of the solderman, it is clear that either relations between wireman and solderman affected the quality of the latter's work, or else relations between wireman and inspector affected the inspector's *judgement* of the solderman's work. This is on top of the fact that different inspectors had different rates of rejection even on the same solderman's work to the same wireman's wiring. Incidentally, it is of interest that the investigators accepted that ' objective ' defects were not affected by the inspector's judgement, for it was in this very factory that a much later experiment (described above) showed that the average ' catch ' by inspectors of objective soldering defects was only 83 per cent (Jacobson 1953).

This evidence strongly suggests that interpersonal relations in the immediate work ' nodule '—the nodule in this last case being inspector–solderman–wireman—may considerably affect inspectors' judgements. But the importance of these interpersonal relations is easily overlooked. It seldom happens that the same operators have their work inspected for the same faults by different inspectors, in the way that happened in the Bank Wiring Observation Room. This means that the possibility never becomes apparent that the operator might

make different defect scores at the hands of different inspectors. So the inspector's different standards, springing from and then perhaps perpetuating his different relations with different operators, are inherently unlikely to be noticed.

The inspector's judgements may also be affected by his relations with, for instance, the repairman. If the repairman has little work on hand, and the inspector is friendly, then the latter is likely to find him work by rejecting a few products. When the repairman has as much as he can cope with, then the inspector is likely to lower his standards, unless he is at odds with the repairman. Thus, the Chief Inspector of one factory, discussing the possibility of a bonus scheme for his final inspectors, said " If I say to them ' the more products you handle the more you'll earn ' they can increase their earnings, and at the same time increase the earnings of the repairers, by rejecting more products. If I pay them on products they pass, then they'll pass every borderline one ". Supposing we add the possibility that the final test might be a very subjective one, yet with vaguely defined standards and, therefore, entrusted to the ' experienced men ', it will be seen that reasons for inspector inaccuracy, simple when taken one by one, can build up into an imposing complexity.

Similarly, if ' accepted ' products are immediately packed, and the packers are on bonus rates, there is a pressure on inspectors not merely to inspect products faster but to pass them. A complication arises if the inspectors have no share in the output bonus. They then argue that they are ' working at an incentive speed for a time rate of pay '. If they feel that the packers' earnings are disproportionately high, and compare invidiously with their own pay as inspectors, then it is reasonably likely that they will become biassed towards rejecting borderline products rather than passing them.

Underlying all this is the general structure of the relationship of inspection with production. Each department has its own interests and its internal loyalties. Within the inspection department these ties may be very close. One reason is that inspectors are comparatively thin on the ground—outnumbered probably ten times by production people. Also, inter-communication between inspectors is intensive; the argument is that an inspector must know about any snag that has occurred in an earlier process so that he can be alert for its possibly causing unusual faults in a later one. Moreover, inspectors tend to have more chances of getting around the works than the production man, whose movements are much more restricted.

Inspectors need this solidarity because their relations with production are often strained. This is hardly surprising, since inspection is a control function relative to production, with the task not only of seeing whether work does or does not conform to specifications, but also of accepting or rejecting it. Rejection obviously makes it harder for production people to reach their output schedule, and to meet their cost budget. What is more, inspection also has to report to higher authority what level of conformity production is achieving; this reporting function does not endear the inspector to the production man. Again, inspection differs from other control functions such as output schedules and cost budgets in that it concerns itself with the actual performance of the work rather than with the limits of time and cost in which it must be done. So inspection's control is a rather intimate one, with considerable likelihood of running up against people's feelings of self-esteem.

In total, the dice are loaded against easy relations between inspection and production, so long as inspection is given all these functions. Moreover, although the inspector has a superordinate function, he does not have the direct authority which would support it. This tends to cause resentment unless the production man can feel that the inspector has some attribute that 'justifies' him—to the production man's eyes—in having this essentially threatening function. The situation is less invidious when the inspector has such 'justifying' attributes as longer service, greater experience, or obviously fuller qualifications than the production man. These can give the production man—in the Chinese phrase—'a ladder to climb down on'. In practice, however, we often find that such ladders are not provided. In their absence, the production man tries to find other ways of saving face, for instance by arguing, or taking his own time in correcting the process, or by 'proving' that he can 'slip something over' on the inspector whenever he likes.

Inspectors are very much aware that many production people resent them. When patrol inspectors were asked "What do production people think of inspection in this factory?" the great majority replied to the effect that inspectors were regarded unfavourably, as Table 1 shows.

Table 1. Responses of 62 Patrol Inspectors from 3 Different Factories to the Question "What do Production People Think of Inspection in this Factory?"
All Figures are Percentages

Factory	Favourably	Middling	Unfavourably
A	17	46	37
B	16	16	68
C	17	55	28

Thus, for one reason and another, inspectors tend to see themselves—rightly or wrongly—as leagued against a hostile world. Production people often feel this way, too. This results in a strong tendency for the supervisor on each side to identify himself first of all as a production man or as an inspector, rather than as a supervisor working for the common good of the concern. If an inspector has a set-to with a production charge-hand and is worsted then he calls in his own charge-hand, but it is in the first place for support, rather than for arbitration. If the inspection supervisor in fact 'arbitrates'—rather than supports—and in doing so goes against his inspector, the inspector complains bitterly that he is 'not backed up by the supervision here'. But much more often does the inspection supervisor take the same line, and see himself as an inspector first, if of rather heavier calibre, and only very much secondarily as a supervisor over inspectors.

§ 6. Problems of Examining Inspector Accuracy

So far we have argued that inspector accuracy is affected by at least three sets of factors: the basic physiological and psychological abilities of the inspector in relation to the demands of his task; factors of 'formal organization' such as the training given to inspectors, instructions, definition of standards, the physical environmental conditions, and the set-up of the actual task itself; and finally factors of interpersonal relations (between inspector and operator, and also, on occasion, between inspector and other apparently not involved people), and of general social relations. According to circumstances, one or

other of these sets of factors may take on greater importance. Thus, some inspection tasks are carried out in almost laboratory-type seclusion, for instance in a separate viewing-room, with little interaction between inspectors and production people. Here the first two groups of factors would be important. But other tasks involve the inspector in close interaction with production people all day long. Here the third group of factors, those of interpersonal relations, will be the most important.

A vital point here is that the 'secluded' type of inspection is becoming less and less useful. All the emphasis now is on using inspection data to obtain quick correction of the process, rather than to sort the results of the process. This involves more and more 'in-process' inspection, done by patrol inspectors in close and frequent interaction with production people. This must increase the importance of factors of interpersonal and social relations. It does not reduce the importance of the other factors; rather does it mean that whereas in the past it was often possible to ignore the third set in managing inspection, the trend of events makes it impossible now.

This raises another point, namely that the consistency of patrol inspectors is inherently difficult to check. Perhaps this is why so many of the studies that have been made have involved simple 'viewing' tasks, the results of which, people can persuade themselves, matter little. But, many of the tasks described above are tasks that are often done on a patrol basis. Moreover, inconsistency has been demonstrated in judgements by the most 'experienced' and 'responsible' men, and even by inspection supervisors themselves. Our observations seem, then, to be relevant even in the most advanced approach to inspection.

Turning now from immediate causes of inaccuracy to underlying reasons why inspector inaccuracy is so often left unexamined, perhaps the first point is the difficulty of making a closely controlled test. Moreover, unless the check is 'built-in' to the flow of work, then inspectors may change their standards when they know a check is being made. In our experiments, the inspectors knew an experiment was being run; so their rejection rates may not reflect their every-day rates. This does not invalidate our demonstration of inconsistency; rather does it make the inconsistency more impressive since the inspectors were presumably on their mettle.

One approach to 'building-in' the check is to put through from time to time a batch of work with deliberately introduced defectives. The proportion of errors discovered gives a measure of accuracy of inspection. But the defectives must be easily identifiable by the experimenter, without spoiling the test. One method, used for example by Belbin (1957), is to stain them with invisible dye that fluoresces under ultra-violet light; thus the inspector's 'accepts' and 'rejects' can later be quickly checked. Similarly to determine the accuracy of inspecting brass screw inserts (Forster-Cooper 1954), 'blind' inserts were deliberately introduced into each batch. But these were made of steel, and brass plated; thus, mis-sorts could easily be picked out by means of a magnet. Another device of Belbin's, this time in examining small steel balls, was to arrange that the defectives—as well as having the defect being looked for—should also be imperceptibly smaller. Obviously, there are various ways by which these smaller balls could later be separated out. In the deliberate error method, of course, only the accuracy of spotting that type of error that is deliberately introduced, can, strictly speaking, be measured.

In any test it is not enough simply to compare totals rejected. Each part must be individually identified, or else different inspectors can reach the same total by rejecting quite different articles. Thus, in one micrometer measuring experiment there were 3 defectives in the batch of 50 parts. In the test, the three inspectors each rejected 3 parts, giving a comfortable suggestion of accuracy. But in fact only inspector A was correct; B rejected 2 defectives and 1 good part, missing 1 defective, while C rejected 1 defective and 2 good parts, missing 2 defectives. Thus only 1 part was rejected in common, out of the 3 actually defective. In total, in the three trials of this experiment, involving 9 inspections of the batch, the ' catch ' was no better than that one defective was caught on 6 out of the 9 occasions, another was caught 5 times, and the third only twice in the 9 inspections.

Besides the practical problems of testing accuracy, there may be very human resistance by inspectors. The inspector is no happier than any of us about entering a situation which might cast doubt on his ability to do his job. Moreover, if the test is made by someone other than the inspection supervisor, the latter, too, becomes anxious since the tester then moves into the same commanding position relative to inspection as inspection usually holds relative to production.

Again, some inspectors undoubtedly feel not only that an accuracy check is somehow inconsistent with the role of inspector but also that it threatens their position relative to production people. It seems that if the inspector chooses to play his role as authoritative, as infallible, then a test of his accuracy, or his acceptance of ' continued ' training, may indeed undermine him. But the role can also be played as fact-finding pure and simple, as a technical job, providing production people with vital working data. In this case, to find that a given task has a ' probable index of inspector accuracy ' of something under 100 per cent is not so much derogatory to inspectors as simply another fact about controlling conformity.

Another point is that inspection supervisors can become too ' product-minded ', if not ' product-bound '. Clearly, the basic task of a supervisor is not to make the product himself but to train and organize other people to make it. The task of the inspection supervisor is to train and organize inspectors to inspect. It may be true that every supervisor's task has its ' inspection ' component, but this is to ' inspect ' that his instructions have been carried out. The inspection supervisor's ' inspection ' task—as a supervisor—is to check, not the products, but the inspection of them. But products themselves offer something concrete and tangible to concentrate on; re-designing an inspection task, or an examination of lighting, or arranging supervised practice for inspectors, apparently offers less to ' get a hold of '. Thus, by and large, the inspection department may see more to gain and less to lose by directing its concern on ultimate products made by someone else than by examining its own efficiency.

On a étudié les causes d'inexactitude du travail des vérificateurs, classifiées dans trois groupes principaux: capacités individuelles fondamentales, organisation formelle (instruction, ordres, conditions physiques, étude de la tâche), et relations entre personnes ou relations sociales. Sans nier l'importance des capacités individuelles fondamentales des vérificateurs, qui doivent déterminer les limites ultimes de l'exactitude, il parait que les limites réelles dans une situation de travail sont déterminées par les deux autres groupes de causes. Ces limites pratiques peuvent être beaucoup plus étroites que celles déterminées par les fonctions psychologiques et physiologiques fondamentales. Par exemple, en cas d'un vérificateur doué de compétence et aptitudes tout-à-fait

suffisantes pour exécuter la tâche de vérification, il est certain qu'il ne peut travailler avec une exactitude plus grande que celle déterminée, par exemple, par les ordres reçus. De plus, même s'il avait été bien choisi et instruit, il ne peut être plus exact que ne le permettent les forces des relations interpersonnelles et d'autres relations sociales. Ces relations interpersonnelles ne le forcent pas toujours d'accepter une tâche qui devrait être rejetée: elles peuvent le forcer de rejeter une tâche qui devrait être acceptée. D'autre part, l'homme de production va désirer voir tous les produits acceptés et de duper le vérificateur quand il ne peut pas l'approuver. Ceci peut, à son tour, forcer le vérificateur de rejeter une proportion plus grande de la production venant de l'homme qui essaie de le duper, que celle qui est à rejeter en réalité. Ces relations interpersonnelles et sociales deviennent de plus en plus importantes, quand la tâche de la vérification devient plus 'socio-technique', impliquant interaction directe avec la production.

Il parait que, lorsque les relations entre la production et la vérification sont mauvaises, lorsque la production sait qu'elle ne peut pas approuver les vérificateurs et/ou leurs normes, et lorsque la vérification veut jouer son rôle d'une manière dominatrice, péremptoire et essentiellement blessante, au lieu d'établir des faits objectifs, l'exactitude du vérificateur souffrira non seulement une influence défavorable, mais il y aura de fortes tendances contre les inspecteurs des vérificateurs, qui examinent l'exactitude du travail de leurs vérificateurs. Quoiqu'il est bien naturel que l'homme qui doit vérifier l'exactitude des vérificateurs devrait être leur inspecteur, il y a de puissantes forces contre cette activité. Non seulement il y a des difficultés d'orde pratique, mais aussi doit-on envisager le fait que les inspecteurs du contrôle etc. ont une tendance de devenir des 'esclaves de la production', même s'il s'agit de négliger leurs devoirs essentiels de vérification. De plus, les pressions des relations interdépartementales encouragent les inspecteurs du contrôle à se considérer en premier lieu comme vérificateurs, et seulement en second lieu comme inspecteurs.

La conclusion générale est que l'exactitude du travail des vérificateurs dans une situation du travail est déterminée par toute une gamme des facteurs. Donc les problèmes d'inexactitude doivent être examinés dans un contexte plus large que celui fourni par un abord simple.

Man hat die Gründe der Aufsichtsungenauigkeit von folgenden drei Standpunktuntersucht : individuellen Grundfähigkeiten, formellen Organisation (Ausbildung, Anordnungen, physische Bedingungen, Arbeitsplan), und menschlichen und gesellschaftlichen Beziehungen. Ohne die Wichtigkeit der individuellen Grundfähigkeiten der Aufseher, die endgültigen Grenzen der Genauigkeit bestimmen, zu verneinen, scheint es, dass die wirklichen Grenzen in einer Arbeitslage durch die zwei anderen Gruppen von Gründen gegeben sind. Diese praktischen Grenzen können sich weit innerhalb der druch grundlegende psychologische und physiologische Funktionen bestimmten befinden. So z.B., wenn ein Aufseher sehr gute Grundfähigkeiten und Begabungen für die Aufsichtsarbeit besitzt, kann er doch nicht genauer arbeiten, als z.B. seine Anordnungen es ihm erlauben. Des weiteren, sogar wenn er gut auserwählt, ausgebildet und instruiert ist, kann er nicht genauer arbeiten, als dies die Drange der Beziehungen zwischen Personen und anderer sozialen Beziehungen erlauben. Diese Beziehungen zwischen Personen veranlassen ihn nicht natwendigkeit eine Arbeit zu genehmigen, welche nicht anerkannt werden sollte ; sie können ihn ebensogut veranlassen, eine Arbeit nicht anzuerkennen, welche genehmigt werden sollte. Umgekehrt wird der Produktionsarbeiter ein Verlangen haben, die Produkte genehmigt zu sehen und den Aufseher zu betrügen, wenn er nicht anerkennt. Diesveranlasst den Aufseher einen grösseren Teil der Arbeit des Mannes, der ihn betrügen will, nicht anzuerkennen, als dies wirklich der Arbeitsqualität entspricht. Diese Beziehungen zwischen Personen und soziale Beziehungen werden immer wichtiger, wenn die Aufsichtsarbeit mehr 'sozial-technisch' wird, d.h. mit unmittelbarer Wechselwirkung mit der Produktion verknüpft ist.

Es scheint, dass, wenn die Beziehungen zwischen Produktion und Aufsicht schlecht sind, wenn die Produktionsabteilung fählt, dass sie die Aufseher und/oder deren Normen nicht anerkennen kann, und wenn die Aufsichtsmänner ihre Rolle anmassend, gebieterisch und in gehässiger Weise spielen, statt die neutralen Tatsachen ausfindig zu machen, die Aufsichtsgenauigkeit dann nicht nur beeinträchtigt wird, sondern es machen sich starke Tendenzen gegen die die Genauigkeit ihrer Aufseher kontrollierenden Inspektoren bemerkbar. Obwohl der Inspektor natürlich der richtige Mann ist, der die Genauigkeit des Aufsehers untersuchen soll, gibt es starke Tendenzen gegen die Ausführung dieser Pflicht. Es gibt nicht nur praktische Schwierigkeiten, sondern auch die Tatsache, dass die Oberaufseher und andere Inspektoren eine Tendenz haben, zu 'Produktionssklaven' zu werden, sogar wenn dies mit der Unterlassung ihrer wirklichen Inspektorpflicht verknüpft ist. Ausserdem wirken sich diese Kräfte der Beziehungen zwischen den einzelnen Abteilungen so aus, dass die Oberaufseher sich selbst in erster Linie als Aufseher, und erst in zweiter Linie als Oberaufseher betrachten.

Die Gesamtschlussfolgerung ist, dass die Aufsichtsgenauigkeit in einer Arbeitslage von vielen Faktoren bestimmt wird. Die Probleme der Ungenauigkeit dürften in einem breiteren Kontext studiert werden, als dies durch eine einseitige Betrachtung erzielt werden kann.

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PROBLEMS OF PIANO PLAYING

By Sidney Harrison

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This paper is based on a talk given in the B.B.C. programme *Music Magazine*. It is reproduced here with only those changes made necessary by the original having been illustrated at the piano. Anyone who has studied human performance will recognize that the penetrating analysis achieved by the author suggests analogies far beyond the skill he discusses.—Editor.

First of all, how do you play a note? Push the key down quickly and you will get a loud sound. Push it down slowly and you will get a soft one. Push it down too slowly and there will not be enough momentum to make the hammer reach the string, in which case you will get no sound at all.

There, it would appear, is the science of piano-operating, and we need have no nonsense about beauty of touch and tone. We may agree that the pianist should not slap the keys flat-fingered, for this would mix noise with music, and he must not bang the piano in the attempt to obtain louder sound than it is designed to produce. But the basic principle would seem to be that beauty of sound is built in. All that the pianist can control is loudness (within limits) and duration (remembering that every sound is a diminuendo and that high notes are short-lived).

If a pianist tries to argue that there *is* such a thing as beauty of touch you can easily prove him wrong by a two-note demonstration. Ask him to play a note softly and nicely. Then ask him to play the same note *equally softly* but not nicely. Make sure he does not cheat: a pianist demonstrating 'ugly' tone nearly always plays louder.

All that the piano 'knows' is how violently the hammer hits the string and just when the damper returns to cut off the sound. (The damper rises from the string when you play a note and stays off until your finger lets go.) All that the piano 'knows' is that if you depress the sustaining pedal the sound of one note will be enriched by sympathetic vibration from other strings and that it will continue even after the finger is released.

The piano knows nothing about the pianist's gestures in the air above the keyboard.

This is the point where people of a mechanical turn of mind usually stop. They have investigated a note. But music does not consist of a note.

I began with the proposition that if you push a key down quickly you will get a loud sound. If this is true, how do we explain the action of a pianist who is playing a very fast piece very softly—*prestissimo, pianissimo*? Can it be that each key is given a shallow push which, though quick, does not follow the key down to its bed? If this is so, the key will slow itself in the last part of its descent. Or is it that muscles take time to get going?

Consider playing very quickly from A to B. At a given moment one muscle is pushing A down and another muscle is preparing to pick up this same note. And the down-B muscle is already thinking of taking over. The two A muscles, down and up, are so coordinated as to make the key-descent not as fast as you

think. And the B muscles are so alert and ready as to make the *succession* of events incredibly quick.

I offer this explanation undogmatically. The mechanism of pianists is not as standardized as the mechanism of pianos (you have only to study hands to begin with) and there are differing schools of thought in teaching and training. Anyway we are confronted with the possibility that when actions are quick, a given action may be slow.

And then we must consider that when action appears to be slow—as when a pianist comes down ' ponderously ' on to a chord—the key-descent may be quick because of a final swing and plunge that is not visible to the audience. Indeed this final swing into the key often distinguishes the ' real ' pianist from the ' ordinary ' pianist. A timid pianist will rush towards a distant note, slow down, make sure, and then push. A bold pianist will move with laconic ease, with an accelerating swing as he homes on to the target.

All his actions are governed by experience based on practice and teaching. If he is approaching an ' exposed ' high note he will be careful not to hit it too hard, even in a fortissimo, because he knows that, even on the best of instruments, the rule for tone is : the higher the worse. But if he is striking a chord he will know that, since the force is distributed over several notes, not one of them will reach the dangerous intensity. Here the rule is : the bigger the chords the louder you can bang them (if the composer agrees).

At this point, we approach the subject of beauty of tone. Beauty resides in contrasts. How loudly can you play a soft melody without seeming to be loud ? This is called ' bringing out the melody ' or playing with *cantabile* touch. How softly can you play an accompaniment without throwing away the interest of the harmonies ? How much difference should there be between accented and unaccented notes ? How often should one use the pedal to ' colour ' the tone ? (*The* pedal is the right-hand sustaining pedal. The soft pedal is used relatively rarely.)

It is also surprisingly true that flexibility in timing the beats often produces an impression of beauty of tone. It is difficult to explain this in words ; but suppose, when with your girl-friend, you want to say ' I love you : how sweet you are ', you might do well to linger on the consonants that begin the words *love* and *sweet*. (I lllove you : how sssweet you are.) The man with an ordinary voice who knows how and where to linger may prove more captivating than the man with a fine timbre who does not know the tricks of speech. So it is in piano-playing. The man who knows where and how to linger on an upright piano may appear to produce better ' tone ' than his less skilful rival playing on a concert-grand.

Perhaps one should not be too surprised at this. The piano, for all its ' singing ' qualities, is a percussion instrument, and timing is of the essence.

What of the pianist ? The pianist is a mixture of athlete and mime. When I was a little boy I used to sit on the edge of the piano stool because I wanted to put my right foot on the pedal. I put my left foot under the stool. I liked to feel the floor with my right heel and my left toes, and then I was athletically poised. With some modification this is still my basic position.

As an athlete I must be able to play with the whole of myself—playing from head to toe. I must also be able to sit still and punch from the shoulder.

I must be able to tap with the forearm and hand. I must be able to hold the arm still and make those highly artificial and unnatural actions of the fingers that are required in scale-playing.

When I say that I hold my arm still, I may mean that I refrain from vertical action but carry the arm along horizontally as I play from the bottom of the scale to the top. And I must know the twisting actions that are something like screwdriving ; and wrist-circling ; and key-stroking (whether by push or pull of the arm).

I must also know that there is more in relaxation than ‘ thinking loose ’. For example, if I decide to hold a chord with the fingers it will be possible to relax the arm provided the fingers do the work of maintaining ‘ grip ’. But if I decide to hold a chord with the pedal, I can relax the fingers provided the arm does the work of holding itself up.

The problem of action and relaxation, as far as the arms are concerned, is very much as in playing games. I time and aim my swing. Where possible, I try to keep the swing going in a follow-through. This may involve some key-stroking en route which, though it does nothing for the piano, does a great deal for me. (On the golf course, the follow-through after a ball has taken flight does nothing for the ball but a great deal for the player.)

Unfortunately these principles do not apply to finger action. You can swing your arms : you cannot swing your fingers—just as you can swing your legs but can only twiddle your toes. A finger must be put down and picked up, and the picking up is often the harder part of the job. It is almost as though a soldier marking time had to be taught not only to stamp down but to stamp up.

Hammers and strings are one approach. Athletics and drill are another. Now for mime and gesture. The teaching of action is often done by the use of emotional language. I have already mentioned how lateness of timing may appear to produce sweetness of tone. In teaching, one must often seek sweetness of tone first and explain the lateness of timing afterwards. I know one woman teacher who has remarkable success with little girl pupils. Like this : “ Now, darling, when you get near the end of the phrase I want you to *love* the C-sharp.”

To love C-sharp, the child approaches the note with especial care (lateness) and strokes the note (lingering). In cold blood you could say that the note began late and ended later. But there are times when warm blood is better. At five years of age you do not want to know why loving the note produces a nice effect. Indeed many girls never do want to know, and many women teachers are content to feel that loving the note is nice, never mind why.

Some men teachers are just the opposite. They cannot see why the trick should work and therefore they deny that it does work.

For these reasons it is often true (not, of course, always) that genteel women produce pupils who make all music sound like Schumann’s *Scenes of Childhood*, while pedantic men train their lads to make everything sound like Czerny’s *101 Exercises.*

I must not forget to mention the circling-wrist actions which are part of every good pianist’s repertoire of action though usually more obvious amongst women than amongst men.

Suppose your right hand is playing a singing melody from B to A. You play B and start to circle anti-clockwise—past 3 o’clock, past 12, past 9. As

you come to 7 you begin to play A. Passing 6 o'clock you are holding both notes; but as your wrist begins its upward swing you let go of B. There is, then, a moment of ' smudge ' when the end of one note merges into the beginning of the next. This is *legatissimo*—smoother than smooth—and may be compared with tiptoeing through a sleeping house. It is *after* you have carefully put your forefoot down that you lift your hindfoot up.

The circling wrist acquires its own rhythm of movement and has something of the effect of a flywheel. The reciprocating action of the key is tied up with the rotatory action of the wrist, and the actions flow in smoother succession. Rotary action is often the best therapy for a jerky player.

The circling, caressing, gliding, stroking actions of a pianist playing romantic music all have their emotional connotations, and one of the greatest problems of piano teaching is to know how to strike the balance between piano-operating and feeling the music. To do this, the teacher must study the pupil.

What about studying the composer? Interpretation is beyond the scope of this article, but one's attitude—the general look of you—may alter as you finish a Bach fugue and prepare yourself for a Chopin Ballade. It is often true to say that a pianist sounds the way he looks, and we realize more and more that there is something in piano playing—and probably in games playing—that forbids the scientist to analyse skill without taking emotion into account. He must remember that there is a personal relationship between the player and the composer—however long the latter has been dead.

That, however, is another subject. It is enough for the moment to have mentioned some of the problems of ' piano playing apart from music '.

L'article en question se base sur un discours prononcé dans le programme Music Magazine de la BBC. On le reproduit ici avec les seules modifications, causées par le circonstance que l'original était accompagné de pièces jouées au piano. Quiconque a étudié la performance humaine ne peut qu'avouer que l'analyse profonde de l'auteur inspire des analogies bien au delà de l'art discuté.

Dieser Aufsatz basiert auf einem im Rahmen des BBC-Programms Music Magazine gehaltenen Vortrag. Er wird hier nur mit den Änderungen wiedergegeben, die durch den Umstand hervorgerufen wurden, dass das Original vom Klavier begleitet wurde. Jeder, der menschliche Leistung untersucht hatte, wird anerkennen, dass die vom Verfasser vollbrachte scharfe Analyse auf Analogien deutet, die weit ausserhalb der von ihm erörterten Kunstfertigkeit liegen.

MEDICAL RESEARCH COUNCIL
CLIMATE AND WORKING EFFICIENCY RESEARCH UNIT

Department of Human Anatomy, University Museum, Oxford

This paper, which was prepared by J. S. Weiner and K. A. Provins, is the first of a series of invited articles describing the work of organizations or groups engaged in research in ergonomics. It is hoped that these articles will between them indicate the range of work which is being done and where advice on particular problems may be sought.—EDITOR.

§ 1. HISTORY OF UNIT

THIS Unit, one of the 60 or so research groups maintained by the Medical Research Council in addition to the National Institute for Medical Research at Mill Hill and the Medical Research Laboratories at Hampstead, represents a continuation and fusion of two research teams which were concerned with personnel research during the last war. The team at Oxford—anatomical and anthropometric—under Professor Le Gros Clark, worked on the design of equipment in relation to operational efficiency; the other—physiological, under Dr. E. A. Carmichael at the National Hospital, Queen's Square, London, was devoted to assessing the effect of climatic factors on human performance. The work of these years is described in *Medical Research in War:* Report of the M.R.C. (1939–1945) and *Medical Research* (*History of the Second World War*).

After the war, the anatomical work at Oxford was continued in relation to Service and industrial problems, and anthropometric studies became the responsibility of the Reader in Physical Anthropology, Dr. J. S. Weiner, newly appointed from Queen's Square, who continued to pursue his investigations on problems of climatic adaptation. It was in these circumstances that the two fields of work—the study of operational efficiency in relation to anatomical factors and to climatic factors—became associated in 1948 within the Unit at Oxford.

Apart from those members of the Unit appointed by the M.R.C., the staff (see Appendix) includes workers attached from the Department of Human Anatomy and the National Coal Board; and from time to time visiting workers from the Services and abroad. The Unit has its own electronic and mechanical workshop as well as technical and secretarial staff. There is much pooling of resources with the University Department and the programme of work interlocks to a large extent with the programmes of research in the Department. For example, in Anatomy, common fields of interest comprise studies of muscle action, joint movement, body posture, the cytology and histochemistry of skin (with particular reference to sweat gland function), vascular patterns of skin, muscle and other organs, endocrine and neurological mechanisms in relation to heat regulation; and in Anthropology, studies of physique, anthropometry, body composition and climatic adaptation.

§ 2. AIMS OF THE UNIT

The general terms of reference for the Unit may be stated broadly as comprising ‘Anatomical and Physiological problems affecting man in his working environment’. This field of interest has been surveyed by Sir Wilfrid Le

Gros Clark in his Earl Grey Memorial Lecture (1949) entitled " Fitting Man to his Environment ", and in " The Anatomy of Work ", (1954).

It is important to realize that the M.R.C. Unit, being attached to a University Department, has as its primary aim fundamental work in the fields of functional anatomy, human climatology and anthropometry. At the same time, like several other M.R.C. establishments, it is also responsible for giving help with practical problems in certain aspects of the field of Ergonomics. Questions of importance to industry or to the Services are dealt with in the Unit as necessary by *ad hoc* investigation and such problems are often valuable in suggesting more fundamental work.

Requests for advice from an inquirer in a particular branch of the Services or in industry are accepted after consideration by the Medical Research Council. Such queries are frequently received as a result of a paper given at a Conference or meeting of the Ergonomics Research Society, or following the publication of a report, while some arise through representation of the Unit on committees or sub-committees of the National Coal Board, British Iron & Steel Research Association, British Standards Institute, Road Research Board, M.R.C. Royal Naval Personnel Research Committee, and the M.R.C. Army Personnel Research Committee*.

§ 3. Nature of Research

While the research is generally of a fundamental nature, much of it arises from or has ultimate application to practical problems. Specific requests for advice can be sub-divided into short-term and long-term studies. An enquiry gives rise to research of a long-term character when the relevant information is not readily available and the problem is sufficiently important to warrant a lengthy investigation. The most satisfactory arrangement in such instances is for the industry or department concerned to provide its own specialist research worker (physiologist, anatomist or medical officer) or the money to employ one, and for this scientist to work in the Unit with the part-time help of one or more M.R.C. members of the Unit. This arrangement makes it easier to solve these long-term practical problems while allowing the research worker to take an interest in ' basic ' research. This plan, which has worked well for the National Coal Board and the Services, has now been accepted for research in the Iron and Steel Industry.

Short-term problems can usually be dealt with relatively quickly from past experience or study of previous literature, combined with visits and sometimes *ad hoc* investigations. A rough analysis of 105 queries received during the last three years is given below.

Type of Query Jan. 1955–Dec. 1957 (inclusive)	Percentage of Total Queries
Anthropometry	12
Equipment design and seating	24
Load handling and energy expenditure	12
Assessment of hot environments	9
Efficiency and comfort at different environmental temperatures	14
Protective clothing	5
Other queries	24

* Details of M.R.C. Committees are given in the Annual Reports of the Medical Research Council (London : H.M.S.O.).

In our experience, the most satisfactory outcome to this type of problem has been where the department of the firm or industry concerned has had someone with a particular interest in ergonomics, such as an industrial medical officer or works engineer, to cooperate with the M.R.C. representative.

§ 4. Review of Past Work

A complete list of publications from the inception of the Unit in 1948 until 31st December, 1957 may be obtained on request to the Unit Secretary. In the present section, various aspects of the Unit's work will be discussed to indicate more fully the problems investigated.

4.1. *Anthropometry and Functional Anatomy*

A considerable number of ergonomic problems have involved the use of anthropometric data, but in relatively few cases have they required systematic research of the type which calls for publication in scientific journals. The results are usually submitted to those concerned in the form of a report. Enquiries have sometimes necessitated small surveys to obtain measurements not otherwise available, such as standing elbow height and maximum vertical reach in relation to the design of canteen kitchen equipment, or on special populations such as school children in relation to the design of school furniture (B.S.I. 1955, Roberts 1956). Applications have frequently compelled consideration of a wide range of working postures such as those adopted in sighting tasks involving extensive movements of the head and trunk (Weddell and Darcus 1947), or the limitations of reach employed in operating a telephone switchboard (Darcus *et al.* 1951).

The development of a photogrammetric method by Tanner and Weiner (1949) and the late Dr. Geoghegan (1953) has enabled a library of photographs of over a thousand individuals to be compiled for reference purposes. Many measurements have already been extracted and successfully applied to practical questions, such as the sizing of men's shirts, dimensions of railway carriage seats and other problems which would otherwise have entailed special surveys (Roberts 1956).

The importance of limb position in enabling the operator of machine controls to use his maximum muscular force has been demonstrated in a number of investigations and stressed in the review by Le Gros Clark (1954). This principle has been employed in designing a special type of seat for use in naval vessels subject to violent motion, so that the seated operator can steady himself by exerting counter pressure between the backrest and a suitably positioned footrest (Darcus and Weddell 1947). A similar arrangement has been incorporated in another seat designed for an experimental tractor for horticulture.

The effect of limb position has also been studied in relation to the maximum forces which can be exerted on a handwheel by the two hands simultaneously (Provins 1955 a). It was shown that while the absolute position of the control or even the plane of operation is relatively unimportant, the joint about which the movement is made is critical. These findings were confirmed using the criterion of maximum endurance. It has also been shown that the maximum forces which may be exerted in a cooperative movement of the two sides about

the elbow or shoulder joints may be predicted from data available for one side only, provided adequate body support is available (Provins 1955 b).

Many other studies of the range and strength of joint movement have been reported which provide fundamental data for the prediction of human performance in operating manual controls. For example, the strength and amplitude of pronation and supination of the hand (Darcus 1951, Salter and Darcus 1952, 1953, Darcus and Salter 1953), strength of elbow flexion and extension (Provins and Salter 1955) and the effects of training on muscle strength (Darcus and Salter 1955, Salter 1955 a), while a critical review of methods of assessing muscle and joint function has been published by Salter (1955 b).

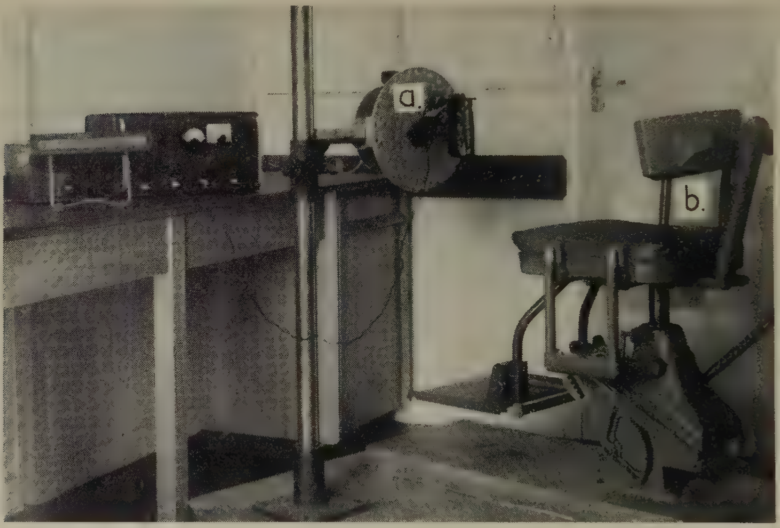

Figure 1. Strain-gauge dynamometer (*a*) developed for measuring amplitude, force and duration of joint movements. The adjustable seat (*b*) is a version of the Universal Seat developed for the Royal Navy.

Measurements of the relative speed, strength, amplitude or accuracy of limb movements on the two sides have been reported by Salter and Darcus (1953), Darcus and Salter (1953), Provins and Salter (1955), Provins (1955 b), Darcus and Salter (1955), Provins (1956, 1958). Within the limits of these studies, no difference has been demonstrated between the two sides in accuracy of movement, little or no difference in amplitude or strength (up to about 5 per cent) but a marked difference in tasks demanding speed of serial movements.

Complementary to these studies of individual joint movements, a force-analysis platform has recently been devised by Whitney (1958) to investigate the efficiency of different working postures in manual lifting problems. Preliminary investigations suggest that limitations in maximum lifting capacity are more likely to be related to certain features of the posture adopted than to muscular strength. Detailed studies of the standing posture and of load carriage are now being made with this method which also offers a fresh approach to fundamental problems of the mechanics of muscle action in man.

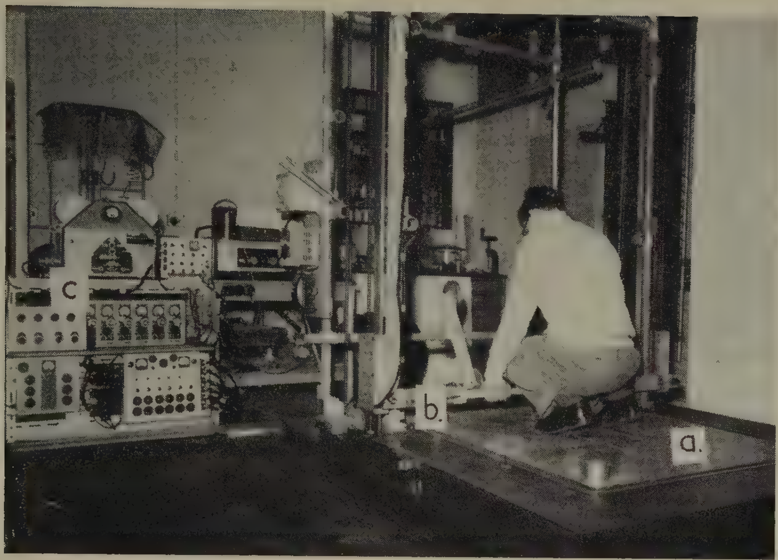

Figure 2. Force Analysis Platform for determining the strength and direction of forces developed during complex and rapidly changing patterns of movement; (*a*) is the strain-gauge platform and (*b*) the vertically movable bar for recording forces at the hands; the 12-channel recording galvanometer and amplifying system is shown at (*c*).

4.2. *Heavy Muscular Work and Environmental Temperature*

Investigations on problems of heavy muscular work and environmental temperature have covered a variety of topics from detailed studies of the neuro-hormonal control of sweat gland activity (Hellmann 1955) to the effect of local and general body cooling on peripheral blood flow and muscle strength (Wyndham and Wilson-Dickson 1951, Lind and Samueloff 1957, Clarke *et al.* 1957), and the classification and coding of heat illness (Weiner and Horne 1958). In most instances they have been related to specific problems for the fighting services and industry, particularly coal mining.

The practical importance of studying sweat gland activity has been made clear by the frequency and extent to which it has been advocated as a measure of thermal stress, and for its role in the maintenance of the salt and water balance of the body, disturbances of which even in a minor degree can lead to marked inefficiency and ill-health (Weiner 1950). The loss of salt and water by sweating has therefore been followed under different conditions of temperature, humidity and air movement (Weiner and van Heyningen 1952 a, b, van Heyningen and Weiner 1952 a, b). An analysis of sweat from the general body surface has demonstrated that, irrespective of acclimatization, the sweat chloride loss is governed by the dietary intake and that salt balance can within a few days be attained with a high or low chloride diet, although the re-equilibrium on a low salt intake was found to be attended by unpleasant effects (Weiner and van Heyningen 1952 b).

The effect of sweat on the corrosion of metal has been studied in relation to assembling and packing operations in industry. It has been found that variations in both the quantity and composition of palmar sweat contribute to the amount of corrosion (Collins 1957). Factors which determine the activity and fatigueability of the sweat gland as well as the composition of sweat have

been the subject of systematic investigation by van Heyningen and Weiner (1952 a, b), Weiner and van Heyningen (1952 a, b, c), Hellman (1955), and Collins *et al.* (1958).

The amount of sweating in four hours has been used as a physiological index of thermal stress by McArdle *et al.* (1947) and a predicted four hour sweat loss (P4SR) of 4·5 litres suggested as the maximum tolerable limit of endurance for fit acclimatized young men. The superiority of this index over the effective temperature scale under conditions of severe heat has been demonstrated by Lind and Hellon (1957). However, in some exceptional industrial conditions such as mines-rescue operations where the combination of environmental and metabolic stress is so great that it is outside the range of prediction of the P4SR scale, a simple index of tolerance time to heat stress using wet and dry bulb readings has been calculated, based on observed survival times using as an experimental end-point a rectal temperature of 101·8°F (Lind *et al.* 1956).

Attention has been given in a number of investigations to the effects of age on responses to high temperatures. No difference in tolerance time to heat stress was found between two age groups of very fit men tested (Lind *et al.* 1955), although evidence of slower sweating responses and increased forearm blood flows with age have been found (Hellon, Lind and Weiner 1956, Hellon and Lind 1956).

In all recent investigations requiring measurement of forearm blood-flow, the mercury-in-rubber strain gauge plethysmograph devised by Whitney (1953, 1954 a) and further validated by Clarke and Hellon (1957) has been used. This method of measuring changes in limb volume is much less cumbersome than the usual water and air plethysmograph and can often be used during working activities.

Physique in relation to heat regulation at high temperatures has been studied on 94 men. Increasing weight was accompanied by an increase in the weight to surface-area ratio and an increase in sweat rate per unit area which was of the same order as the increase of heat production with weight when step-climbing (Hellon 1957).

The importance to industry of studies of acclimatization to hot atmospheres has been stressed in a survey of the field by Weiner (1950), while Hellon, Jones, Macpherson and Weiner (1956) have shown that the differences in response to exposure to heat of subjects living in the tropics and subjects living in the United Kingdom may be explained in terms of a physiological adaptation which is identical with artificial acclimatization produced experimentally. Other studies on acclimatization have been carried out by Wyndham (1951), Weiner and van Heyningen (1952 a, b), Whitney (1954 b), Hellon and Lind (1955) and Hellman *et al.* (1956).

Further investigations have recently been started on the acceptable conditions in underground mining work in relation to age, acclimatization, length of shift and types of work routine. A preliminary discussion of this problem is given by Weiner and Lind (1955).

Le présent article, écrit par J. S. Weiner et K. A. Provins, est le premier d'une série des articles invités, qui décrivent le travail des organisations ou groupes s'occupant des recherches ergonomiques. On espère que ces articles vont comprendre le champ entier du travail conduit à présent et vont indiquer les places où l'on peut obtenir des informations relatives aux problèmes spéciaux.

Dieser von J. S. Weiner und K. A. Provins vorbereitete Aufsatz ist der erste der erbetenen Aufsätze, welche die Tätigkeit von Organisationen oder Gruppen, die sich mit ergonomischen Forschungen beschäftigen, beschreiben. Man hofft, dass diese Aufsätze das Gesamtgebeit der gegenwärtig ausgeführten Forschungsarbeiten umfassen, sowie die Stellen, wo Auskunft über einzelne Probleme erhalten werden kann, anzeigen werden.

Appendix

Present Staff (1958)

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D. P. Thomas, B.Sc., M.B., B.S. (Capt., R.A.M.C.)

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Human Sciences Committee

At the first Symposium held by the Ergonomics Research Society, in 1951, on the general topic of " Human Factors in Equipment Design ", the opening address was given by Sir Ben Lockspeiser, then Secretary of the Department of Scientific and Industrial Research. He drew attention to the way in which some of the D.S.I.R. Research Stations had been led by the needs of the day into the " human factor " field, and particularly into that section lying within the scope of ergonomics ; as had been the cooperative Research Associations under the aegis of D.S.I.R. in their task of providing a scientific service for their respective industries. The D.S.I.R. has continued to show interest in the field of ergonomics, and now comes news of a further development. The Council for Scientific and Industrial Research, the Research Council which controls the work of D.S.I.R., has decided to continue to promote research into the human problems of industry as an established part of its work. It has set up a committee on " Human Sciences in Industry ", with terms of reference to keep under review the development of the human sciences in relation to industrial needs and to advise the Research Council in the allocation of grants and on other means of promoting research in this field.

The Committee is expected to carry on and develop the D.S.I.R. side of the work of the two former D.S.I.R. and Medical Research Council Joint Committees on Human Factors in Industry, D.S.I.R. and M.R.C. having agreed to replace these Committees by separate ones reflecting the different interests of the two Research Councils. The researches sponsored by the former Committees have already provided much material for persons interested in ergonomics ; in particular, projects under the Committee on Individual Efficiency in Industry gave the initial support for the ergonomics sections now well established in the British Boot, Shoe and Allied Trades Research Association and the British Iron and Steel Research Association, while as an example of relevant research in the programme of the Human Relations Committee may be mentioned the project carried out by Edinburgh University on the tensions which arise between inspectors and the persons whose work is inspected, and the ways in which these depend on the technical nature of the product and of the inspection process, as well as on the organization of inspection in the firm. One of the main features of the research programmes of these Committees—from which a steady stream of published results is now coming—has been the intimate connection often shown by the ergonomic aspects of problems with, on the one hand, purely technological aspects, and, on the other hand, with organizational and human relations aspects. The new D.S.I.R. Committee should be well placed to integrate with technological progress the growth of research in ergonomics and other areas of the human sciences of immediate or ultimate relevance to industrial needs.

The new Committee has a membership drawn widely from scientific and industrial backgrounds. Its members are:

Chairman: Mr. L. T. Wright, Member of the Council for Scientific and Industrial Research, General Secretary, Amalgamated Weavers' Association.

Mr. P. W. S. Andrews, Fellow of Nuffield College, Oxford.

Mr. H. Briggs, Labour Adviser to the Personnel Division of Unilever Ltd.

Professor J. Drever, Professor of Psychology in the University of Edinburgh.
Mr. E. Fletcher, Head of the Production Department, Trades Union Congress.
Professor M. Gluckman, Professor of Social Anthropology in the University of Manchester.
Mr. H. G. Jones, Deputy Head of Laboratories, Industrial Group, U.K. Atomic Energy Authority.
Mr. H. G. Nelson, Managing Director of the English Electric Company.
Professor E. A. G. Robinson, C.M.G., O.B.E., Member of the Council for Scientific and Industrial Research, Professor of Economics in the University of Cambridge.
Miss B. N. Seear, Lecturer in Social Sciences in the London School of Economics and Political Science.
Dr. A. T. M. Wilson, Director of the Tavistock Institute of Human Relations.
Secretary: Mr. R. G. Stansfield.

LETTERS TO THE EDITOR

Dear Sir,

I was interested to read Mr. Grime's article (*Ergonomics*, February) concerning safety factors in road transport and especially his views upon the control of the vehicle. In this he mentions the question of powered controls and goes on to say, ' All the old methods of control can therefore, if necessary, be discarded, and replaced by new ones designed to give the driver maximum control of his vehicle '. There is a suggestion here, perhaps unintended, that powered controls are necessarily superior to the ' old methods '. In many cases, in fact, the opposite obtains. Especially is this so in steering mechanisms, where the resulting lack of ' feel ' can be disastrous. In this respect it is interesting to note that in aircraft where the control forces have often been so great that powered controls have become essential, much time and ingenuity have been expended in introducing ' feel simulators '. Whatever the merits of power assisted brake and transmission systems, powered steering would seem to be a retrograde step as regards safety, although it would curtail the actual physical effort required from the driver. A properly designed front suspension and steering system should not need power assistance on any but the really outsize vehicle.

Briarwood,
The Glade,
Kingswood, Surrey.

Yours etc.,
P. J. C. Chapman,
M.B., B.S.

Dear Sir,

Dr. Chapman has criticized my statement on the possibility of improved control methods for road vehicles. It was not my intention to suggest that powered controls for road vehicles are necessarily superior to the ' old methods '. My intention was to point out that a stage had been reached at which the car designer could think anew on the subject of controls, without having to consider limitations imposed by human muscle power. The result of this rethinking might be to confirm present arrangements as the best possible, but I suggest that this is unlikely.

The wheel shape of the steering control clearly arises from the requirement for a large reduction ratio in the gearing, in order to multiply the driver's steering effort. Power steering allows the steering control to be of any form or type, and encourages the designer to take the requirements of the driver as his starting point. A recent paper by Gibbs* suggests that a pressure control system has advantages, and others will no doubt be devised. I think that it would be surprising if nothing better than the present system emerges.

Yours faithfully,
G. Grime,
Senior Principal Scientific Officer
(Traffic and Safety)

Road Research Laboratory,
Harmondsworth,
Middlesex.

* Gibbs, C. B. 1954, The continuous regulation of skilled response by kinaesthetic feed back. *Brit. J. Psychol.*, **45**, 24–39.

SUMMARIES OF PAPERS PUBLISHED ELSEWHERE

Authors of papers of ergonomic interest which have been published in other journals or which are available as privately circulated reports are invited to submit summaries for publication in this Journal. They may be sent to any member of the Editorial Board and should be accompanied by a copy of the full paper which will be returned to the author on request.

PETERS, G. A., and DRUMM, L. R. (1957), Human engineering—a new occupation. *Personnel and Guidance Journal*, **36**, 272–276.

This article analyses particulars of 61 positions in the field of Human Engineering in United States, advertised in six recent employment bulletins of the American Psychological Association. 26 of these vacancies were in private industry, 25 in Government agencies, 9 in consulting organizations and one in a University. Typical job duties were: "To provide engineers with information necessary to design displays and controls, assist technical personnel in the design of experiments, do job analyses and human engineering consultation with research and development engineers during electronic and electromechanical equipment and systems design, conduct appropriate literature searches and design productive experiments on human factors in machine operation; to conduct applied research on guided missile systems, radar, clothing and equipment, electronics maintenance, operator control-display problems, effects of noise, vibration and blast, weapons systems, handling systems, communications analysis, environmental alteration of human capabilities, and work space problems; to prepare clear and understandable technical reports on significant topics; to work with teams involving any of the following: mechanical engineers, industrial designers, aeronautical engineers, physicists, meteorologists, transportation specialists, safety engineers, electronics engineers mathematicians, economists, statisticians, physiologists, anthropologists, sociologists, and physicians."

Average salaries were quoted as from 4300 dollars to over 6000 dollars. Related job titles, academic preparation required or recommended and the current status and possible future needs for human engineers are also briefly discussed.

EMPLOYMENT OF OLDER WOMEN—AN ANNOTATED BIBLIOGRAPHY (Published by the U.S. Government Printing Office, Washington, for the U.S. Department of Labor).

Summaries are given of 81 sources of information each of which covers one or more of three topics, namely hiring practices; attitudes, either towards older workers or expressed by them; and work performance. The latter includes the relation of physical and mental performance to age as determined by laboratory experiments and psychological tests, ' on-the-job ' performances by various age groups and studies relating age to productivity, absenteeism, labour turnover and other criteria of work performance. Special attention is given to sources which deal particularly with the problems of work for older women but many of the references are concerned with the employment of older people without distinction between men and women.

Turner, D. (1958), Heat stress in non-ferrous foundries. *Brit. J. Industr. Med.*, **15,** 38–40.

The results of 98 individual exposures to the environmental conditions occurring in typical non-ferrous foundries are reported. A comparison is made between the rate of heat loss by evaporation predicted from the Belding-Hatch heat stress index, and the rate calculated from the observed sweat losses of the subjects of this investigation. A close agreement between the calculated and observed rates is noted, particularly in the range of environments in which the heat stress reached significant proportions. There is also some evidence to support the view that men will not willingly work for prolonged periods under conditions for which the value of the heat stress index exceeds 100.

McKennell, A. C. (1958), Wool quality assessment: its sensory and psychophysical basis. *Occup. Psychol.*, **32,** 50–60.

Subjects had to match a test sample of wool top against a series of samples under three conditions: touch-and-vision, vision only, and touch only. Matchings by vision only were found to be as good as those based on a combined use of vision and touch. Matchings by touch only were significantly less accurate than by vision only and by vision and touch together.

Single fibre discrimination was investigated, but the speed of assessment by expert graders precludes this as the basis of visual judgement. Subjective assessment seems to be based on some feature of fibre assembly rather than the comparison of individual fibres.

In a third experiment, the paired comparisons method was used to calibrate on a subjective scale wool top samples selected by a firm as representative of their range of qualities. Good agreement was found between these data and those of the matching experiment.

Shackel, B. (1957), Human engineering and electronics. *Brit. Communic. and Electron.*, **4,** 350–356.

This article discusses some aspects and examples of ergonomics and stresses the importance of the subject to the electronic engineer. Recommendations upon the optimum design of controls, displays and panel layouts are summarized from the literature. Some examples are given from recent electronic components and systems.

Shackel, B. (1958), Dial design. *Design*, February, No. 110, 31–35.

This article aims to give to industrial designers specific, detailed advice from the literature of ergonomics upon the functional design of dials. The various principles enunciated are illustrated with drawings and plates of meter scales and vehicle speedometers.

Heron, A. (1958), Psychology, occupation and age. *Occup. Psychol.*, **31,** 21–25.

Some of the problems associated with technological changes, which face the occupational psychologist who is studying the effects of ageing in the industrial population, are outlined.

ERGONOMICS RESEARCH SOCIETY

ANNUAL GENERAL MEETING

The 9th Annual General Meeting of the Ergonomics Research Society was held in Bristol on Monday, 14th April, 1958, at 6.15 p.m. There were 40 members present.

The report of the Hon. Secretary and the Hon. Treasurer showed that the Society continues to flourish. The number of Ordinary Members was 183, with 8 Honorary Members and 19 affiliated Members.

After commenting on the successful launching of the journal *Ergonomics*, the Secretary said that two problems were being considered by the Council. These were 'training in ergonomics' and 'the provision of expert advice on ergonomic problems'. Members of the Society had been closely associated with the European Productivity Agency's Project 'Fitting the Job to the Worker', and Mr. Murrell, who was the member of the E.P.A. team which visited America, had in his report clearly indicated the importance of training and consultation.

In the discussion which followed the presentation of these reports, attention was drawn to the liability of learned societies to income tax as a result of recent decisions in the Courts. Mr. Broadbent proposed and Dr. Cotes seconded the following motion, which was carried unanimously :—

> "To consider the wording of Rule 3 of the Society in order to determine whether any ambiguity exists concerning the charitable purposes of the Society; and, if such ambiguity exists, to prepare an amended rule for submission to an Extraordinary General Meeting, which will make these purposes clear".

The following were elected as Officers and Council for 1958–59 :—

Chairman of Council :	T. Bedford, M.R.C. Environmental Hygiene Research Unit, London School of Hygiene and Tropical Medicine, London, W.C.1.
Hon. Secretary :	O. G. Edholm, Division of Human Physiology, Medical Research Council Laboratories, Holly Hill, Hampstead, London, N.W.3.
Hon. Treasurer and Membership Secretary:	K. F. H. Murrell, Department of Psychology, 22 Berkeley Square, Bristol, 8.
Members of Council :	J. E. Cotes L. V. Green R. G. Hopkinson H. G. Maule Miss A. D. K. Peters Miss I. M. Slade R. G. Stansfield D. Wallis

It was proposed by Dr. Edholm and seconded by Mr. Murrell that Mr. Welford, the General Editor of the Journal *Ergonomics* should be *ex-officio* a member of the Council. This proposal was carried unanimously.

The following were elected as Ordinary Members of the Society :—

Dr. H. Banister
Dr. G. H. Begbie
Mr. C. E. Brooks
Mr. G. A. Courtney-Coffey
Mr. D. G. Entwisle
Mr. R. J. Haerdi
Mr. J. A. Jeffery
Dr. A. H. Jones
Miss G. M. Morton
Mr. J. K. Page

Also elected were the following for affiliated membership :—

The British Thomson-Houston Co., Rugby
The Engineering & Allied Employers' West of England Association, Bristol
Messrs. A. E. Reed & Co., London

The Secretary said that the programme of the present Symposium had been prepared by Dr. Weiner and Mr. Broadbent. It was proposed to hold the next Symposium in Oxford from 6th–9th April 1959, and the provisional title would be ' The Application of Ergonomics '. The organization of the programme would be in the hands of Dr. Cotes and Mr. Wallis.

PROCEEDINGS

A Meeting was held on 31 January, 1958, at The British Boot, Shoe and Allied Trades Research Association, Satra House, Rockingham Road, Kettering, at which the following papers were presented :—

(1) " Ergonomics in the Shoe Industry ", by W. T. Singleton.
The term ' Ergonomics ' is used loosely in that the Ergonomics Department is concerned with anything to do with productivity in the Shoe Industry. The staff consists of psychologists, work-study engineers, development engineers and shoe technologists. There are three sections providing a direct service to the industry :—

(i) Concerned with problems of factory organization and layout.

(ii) Concerned with the work-space layout and controls of particular man/machine systems.

(iii) Concerned with the development and application of operative training schemes.

There are two supporting sections :—

(iv) Concerned with the collection and analysis of all data required by the three ' front line ' sections.

(v) Concerned with the engineering development of ideas being fed from the training and methods study sections.

The remaining section :—

(vi) Deals with any problems which require more fundamental research, again this is fed by the ' front line ' sections.

(2) " Design of Work-Spaces ", by R. J. Haerdi.
These projects normally begin with the study of the orthodox work-space using standard techniques such as two-handed process-charts and micro-motion study. The new work-space is then designed on principles of motion-economy and the improvement of perceptual cues. Anthropometric data is used in calculating the gross dimensions of the revised work-space.

Experimental models are produced and subjected to factory trials. Results often have to be based on operatives' opinions, but where possible ' before ' and ' after ' numerical data are obtained. The design is finalized after taking account of engineering production requirements and the new unit is then made available to all member firms. Two such investigations have been carried out in the past year on work benches for specialist operations.

(3) " Training of Operatives ", by W. T. Singleton.
For the past four years this work has been concentrated on the design and application of a training scheme for sewing-machinists. The scheme developed follows the principles of W. D. Seymour; the objective is to produce machinists skilled on the simpler operations after an intensive training period of six to eight weeks. To date twenty-nine instructors or instructresses have been trained in the administration of this scheme and the majority are now running successful training-schools in factories and technical colleges throughout the country.

(4) " Layout and Control of Sewing-Rooms ", by R. Simister.
New factory layouts and office systems are designed and installed at the request of member firms. This work is very similar to that of management consultant organizations except that no time-study is done and there are other objectives in addition to the normal one of improving efficiency. These include the accumulation of practical experience from which general principles of factory organization can be developed and the careful checking and analysis of results obtained so that the extent and causes of improvement can be identified. It is hoped that these projects can be regarded as large scale experiments in which the main factors governing productivity in departments or factories are manipulated.

(5) " Physiology for the Shoe Industry ", by H. S. Burry.
The following projects were discussed :—

(*a*) The improvement of apparatus for thermal environment studied in factories.

(*b*) Methods for measuring pressures between foot and shoe and for indicating foot to shoe relationships in gait studies using simple pressure and contact elements.

(*c*) The investigation of diurnal variations of foot volume (for a small number of young healthy subjects, the average increase was about 3 per cent in the course of the working day, equivalent to about half a fitting interval in shoe girth).

(*d*) The effect of shoe wearing and of shoe form on development of hallux valgus and the aetiology of the condition.

(*e*) Experiments on thermal effects of footwear.

(*f*) Patch test experiments to determine possible dermatitic effects of certain types of shoe trade adhesives.

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Assistant Editor :

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The ever-widening scope of research in Radiation Biology and its related subjects has accentuated the need for an international journal which would not only concentrate, but also provide further facilities for, publication in this field. At present such articles are scattered over a number of journals in which one would scarcely expect to find them.

The Editorial Board intends to publish original articles, critical reviews and reports of symposia connected with work on the effects of radiation in its widest sense, as far as it concerns biology, whether directly or indirectly.

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> Bartlett, F. C., 1943, Fatigue following highly skilled work. *Proc. roy. Soc.* B, **131**, 247–254.
>
> Bedford, T., 1948, *Basic Principles of Ventilation and Heating* (London: H. K. Lewis).
>
> Le Gros Clark, W. E., 1954, The anatomy of work. In *Symposium on Human Factors in Equipment Design* (Edited by W. F. Floyd and A. T. Welford) (London: H. K. Lewis). Pp. 5–15.

Abbreviations should be as in the *World List of Scientific Periodicals.*

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ERGONOMICS

Volume 1 May 1958 Number 3

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